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A TEXT BOOK OF
BIOLOGY
CLASS XI



N. W. F. P. TEXT BOOK BOARD, PESHAWAR

A TEXT BOOK OF BIOLOGY

CLASS XI



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IDARA FAROGH-E-TALEEM

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for:

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PESHAWAR**

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Authors:

1. Dr. M. Rehan Siddiqui
2. Prof. T.H. Hashmi
3. Dr.M. Sharif Mughal
4. Prof. Wahab Akhtar Aziz
5. Prof. Tariq Mahmood

Editors:

Dr. Shehzad Ahmad Mufti
Dr. Javaid Iqbal
Mrs. Rehana Johar

Supervised By:

Dr. Alam Zeb

Illustration & Art Sketches By:

Takhlique Markaz Lahore.

Published By:

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PREFACE

Curriculum development is a dynamic process. It has to be so, if we are to keep pace with the development in our society. With this view, in early seventies, biology course for F.Sc. students was radically modified. Basically, this modification involved inclusion of recent advances in various disciplines of Biology as well as a change in emphasis from a descriptive to an experimental approach. Unfortunately, no textbook was written in accordance with this change in syllabus. Instead, an American book, entitled "Biological Science an inquiry into life" was introduced as such. This book was quite adequate but there had been persistent complaints about the language used and description of many animals and plants which were not found in this part of the world. Thus, a need to write a book by local authors, including examples and description of local plant and animal species, had been felt throughout this time. Consequently, the curriculum wing of the Ministry of Education, syllabus was prepared by a study group and placed before a National Committee as well as provincial curriculum centres. Finally, a select committee consisting of experts in the subject was constituted to finalize the curriculum. The Biology curriculum, on which this book is based, was the outcome of all these painstaking efforts. It was further recommended that local authors be asked to write a book according to this revised syllabus.

The local authors while writing the book have tried their best to describe various biological principles in an easy to understand language. Utmost efforts have been made to include examples of locally found animals and plants, although it has not been possible in every case. We are quite hopeful that the present book will prove to be a considerable improvement over the "Yellow version" used till now.

In the present coloured edition, most part of the text have been entirely rewritten in the light of comments and criticisms made by the working teachers since the first edition appeared. Suggestions to further improvement the quality of this text book will be gracefully acknowledged.

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

INTRODUCTION

1

THE SCIENCE OF BIOLOGY

Biology is the scientific study of living things, plants and animals. The word 'Biology' has been derived from two Greek words, bios and logos. Bios means life and logos means thought, discourse or reasoning. Biology is subdivided into two main groups called Botany and Zoology. **Botany** is the study of plants while **Zoology** is the study of animals.

WHY STUDY BIOLOGY

The basic use of all scientific information is to improve the quality of our lives. The study of biology is especially important for us because our whole existence and our every day life revolves around basic biological processes. The production of food and our health are two basic aspects of our lives without which we cannot survive. It is through advancements in biology that man has been able to produce food in greater quantities and has been able to control diseases, with the result that we live longer and healthier lives.

Ever since the beginning of civilization, man has been concerned with the production of various kinds of food, especially in the form of various crops such as wheat, maize, rice and barley. In addition, different types of vegetables and fruits were grown to supplement his diet. With the passage of time man used the knowledge of biological principles not only improving the quality and yield of the existing food varieties but also creating some new varieties of food. Biological research in the fields of Genetics and pest control has helped us in achieving these goals. Even today we are creating new varieties of wheat, and of rice, which has helped us to overcome the problems of food shortage. Biological research has also helped us in eliminating many pests which previously destroyed a lot of stored grain. The production of many kinds of pesticides has been very helpful in this direction.

In the field of health, the development of new drugs and vaccines has been extremely helpful to mankind and all this has been possible due to biological

research. The discovery and development of antibiotics by biologists has played a vital role in improving our general health conditions. Many fatal diseases such as small pox, tetanus and diphtheria can now be easily controlled due to the development of vaccines against these diseases. This has resulted in a great reduction in infant mortality. Every day new drugs are constantly being developed by biologists which are helping us in improving the quality of our lives.

Biological research is also helping us in the improvement of our environment. Rapid industrialization during the past few decades has resulted in pollution of our surroundings including air, land and water source. As a result of this pollution not only human beings but also animal life around us including wild life, is exposed to all kinds of harmful effects. It is through biological research that we are trying to find out ways and means to overcome and eventually eliminate the pollutants.

It is thus obvious that biology has a great impact on our every day existence and we must study this science if we are to improve the quality of our lives.

MAJOR DIVISIONS OF BIOLOGY

Biology has been divided into the following main divisions:

1. **Morphology:** **Morphology** is the study of form and structure of living things. The word structure is used for the parts of organisms that can be seen with the naked eye or with a microscope.
2. **Anatomy:** **Anatomy** is the study of internal organs while microscopic study of tissues is called **Histology**.
3. **Cell Biology:** **Cell Biology** is the study of structure and function of cells.
4. **Physiology:** **Physiology** is the study of functions of different parts of plants or animals.
5. **Ecology:** **Ecology** is the study of relationships between organisms and their environments.
6. **Palaeontology:** **Palaeontology** is the study of fossils and their relationships to the evolution of life upon earth.

Palaeobotany is the study of fossils of plants, while the study of fossils of animals is called **Palaeozoology**. **Fossils** are the remains of living organisms or their impressions preserved in the rocks.

7. **Genetics:** **Genetics** is the study of hereditary characters transmitted from the parents to the offsprings.

8. **Taxonomy:** It deals with naming and classification of organisms. Classification means the arrangement of plants and animals into groups and subgroups based on similarities. Closely similar organisms are placed in the same group.
9. **Embryology:** **Embryology** is the study of the development of an organism from a fertilized egg or zygote.
10. **Microbiology:** **Microbiology** is the study of microorganisms.
11. **Molecular Biology:** **Molecular Biology** is the study of structure and function of molecular components of the cells such as proteins, nucleic acids, hormones etc, etc.

Scope Of Biology:

Understanding of biological principles help us to understand ourselves. What we are? What we are made of? What happens inside our bodies and how? How do we interact with our environment? How can we use what is available around us? What happens in our bodies when we fall sick? Answers to all these questions and many more come to us through an understanding of biological phenomena.

RELEVANCE OF QURANIC INJUNCTIONS IN THE STUDY OF BIOLOGY

Islam lays special emphasis on the acquisition of knowledge. All great Muslim thinkers paid special attention towards acquisition of knowledge and attached primal importance to the study and understanding of the Holy Quran. The type of knowledge which the Holy Quran gives is spiritual, moral and quite practical. It lays stress time and again on the conquest of nature through perception and understanding.

Quran invites the believers to go around the world and see its wonders, observe the stars and their movement, to ponder over the mysteries of creation and make an attempt to discover the truth. This invitation is a clear indication of the fact that Islam does not like to have blind following, but instead wishes the people to use their intellect to arrive at the truth by deduction. The Holy Prophet (peace be upon him) said, "Listen to the word of the learned and instil into others the lessons of science, for it is better than religious exercises".

There are numerous Quranic injunctions that emphasize the study of Biology. These describe the study of organisms and their different aspects of life. Modern biologists believe that life had originated in oceans first and then migrated to land. The Holy Quran says:

"Have not those who disbelieve known that the heavens and the earth were of one piece, then we parted them, and we made every living thing of water? Will they not then believe?"
(Al-Quran 30:21).

About the origin of life, it is suggested that life must have begun with some simple cell and with the passage of time it evolved into the plants and animals of today. If there is to be a spontaneous appearance of life, the beginnings must involve some chance association of atoms. The Holy Quran describes the origin of life as:

"Lo' We created them of sticky clay"

(Al-Quran 11:37)

" O mankind' Be careful of your duty to your Lord who created you from a single soul and from it created its mate and from them twain hath spread (like seed) abroad a multitude of men and women."

(Al-Quran 1:4)

It is believed that the primitive earth had an atmosphere of methane, ammonia, water-vapour, hydrogen sulphide and hydrogen. These simple substances gradually combined into complex molecules which served as models for organizing chemical substances around them. In this respect Quran emphasizes:

"See they not how Allah originates creation, then repeats it: truly that is easy for Allah:"

(Al-Quran 19:29)

At so many different occasions Quran stresses the study of different branches of Biology such as Anatomy, Taxonomy, Embryology, Ecology and Morphology, Some of these verses are:

"And He is Who had produced you from a single being".

(Al-Quran 98:6)

"And of every thing We have created pairs: that ye may receive instruction."

(Al-Quran 49:51)

"There is not an animal on the earth nor a being that flies on its wings, but (forms part of) communities like you."

(Al-Quran 36:6)

"It is He Who sendeth down rain from the skies: with it We produce vegetation of all kinds: from some We produce green (crops), out of which We produce grain, heaped up (at harvest): out of the date-palm and its sheaths (or spathes) come clusters of dates hanging low and near: And (then there are) gardens of grapes, olives, and pomegranates, each similar (in kind) yet different (in variety): When they begin to bear fruit, feast your eyes with the fruit, and the ripeness thereof. Behold' in these things are signs for people who believe."

(Al-Quran 99:6)

The following verses urge man to study plants and animals.

"And We sendeth the wind for fertilizing and cause water to descend from the sky".

(Al-Quran 22:15)

"O mankind' if ye have a doubt about the resurrection, (consider) that We created you out of dust, then out of sperm, then out of leech like a clot, then out of a morsel of flesh, partly formed and partly unformed, in order that We may manifest (our power) to you; and we causes whom We will to rest in the wombs for an appointed term, then do We bring you out as babies, then (foster you). That ye may reach your age of full strength; and some of you are called to die and some are sent back to the feeblest old age, so that they know nothing after having known (much), and (further), thou seest the earth barren and lifeless, but when We pour down rain on it, it is stirred (to life), it swells, and it puts forth every kind of beautiful growth (in pairs)" (Al-Quran 5:22)

"And Allah has created every animal from water: of them there are some that creep on their bellies: some that walk on two legs and some that walk on four, Allah creates what He wills" (Al-Quran 45:24)

"Do they not look at the camels, how they are created"? (Al-Quran 7:28)

"Do they not observe the birds above them, spreading their wings and folding them in? None can uphold them except (Allah) Most gracious: Truly it is He that watches over all things" (Al-Quran 19:67)

"Then let man look at his food, for that We pour water in abundance, and We split the earth in fragments, and produce therein corn, and grapes and nutritious plants, and olives and dates, and enclosed gardens, dense with lofty trees, and fruits and fodder, for use and convenience to you and your cattle:" (Al-Quran 24-32:80)

These verses have a special significance and importance for those in the modern times who are influencing into the mysteries of nature and trying to understand its secrets through perception and investigation.

BIOLOGICAL METHODS

The scientists have developed certain methods to seek answers to various questions. A scientist may make a statement which he thinks may be the answer to the problem under study. This statement is known as hypothesis. Taking this hypothesis to be true, certain deductions are made. Deductions are logical consequences of a statement, which are helpful to answer the question/problem. These deductions are then subjected to experiments. If these deductions are proved true, the hypothesis is regarded as correct. In order to understand, let us consider that there is a hypothesis about malaria, that:

"Plasmodium, is the cause of malaria"

We can make, and then test, the following deductions. If *Plasmodium* is the cause of malaria then all persons ill with malaria must have *Plasmodium* in their bodies. To test this deduction, the blood of person suffering from malaria is tested under a microscope. If *Plasmodium* is observed in the blood sample, the deduction

is verified and hypothesis is considered to be correct.

An American scientist A.F.A. King, in 1883, suggested that mosquitoes are involved in the spread of malaria. He listed about twenty observations to support his hypothesis. Some of his observations were:-

- 1) People who slept outside in open spaces suffered from malaria more frequently than those who slept indoors.
- 2) People who slept under mosquito nets did not suffer from malaria.
- 3) Persons who slept near smoky fire did not suffer from malaria.

These observations are insufficient to prove the hypothesis. King himself suggested that his hypothesis could be tested by further investigations. So it encouraged further experiments in order to prove or disprove the hypothesis.

Experiments of Ronald Ross to Understand the Malarial Problem:

After it was discovered that "*Plasmodium*" is the cause of malaria", Ronald Ross discovered how *Plasmodium* entered the blood of man. He discovered *Plasmodium* growing and multiplying in the wall of stomach of female *Anopheles* mosquito after it had bitten a person ill with malaria. In another experiment, he allowed the mosquitoes to bite sparrows suffering from malaria. He killed few mosquitoes after a few days and discovered malarial parasites, growing and multiplying in the wall of the stomach of each mosquito and later in the salivary glands of the mosquito. He then allowed such mosquitoes to bite a healthy sparrow. The parasites were later on found in the blood of sparrow and the sparrow became ill with malaria.

On the basis of above experiments, Ross suggested that a similar relation might exists between man, mosquito and malaria (*Plasmodium*), which was later on confirmed.

Ross used sparrows in his experiment for two reasons:

- i) Sparrow suffering from malaria will show the same symptoms as in man.
- ii) Malarial disease was fatal in those days and he was reluctant to use man as an experimental organism. Ross further discovered that *Anopheles* mosquito carries *Plasmodium* which causes malaria in humans while *Culex* mosquito causes it in sparrows.

History of Discovery of Malarial Parasite

The name malaria is a combination of two Italian words "mala" means bad and "aria" means air. Malaria is the disease which used to exist in the past as well in

countries like Egypt, China, India, Italy and Greece. The physicians, about two thousand years ago, used to describe this as a disease of chill, fever and recurring attacks. It was thought that the disease is due to stagnant water of marshy places which poisoned the surrounding air. When people inhaled this air they suffered from malaria. On this basis the disease was named as malaria.

Early Romans used to drain off the water from marshy places to control the disease.

In 1878, a French army doctor, Laveran, discovered tiny creatures under microscope in the red blood cells of a malaria patient. Some time later, these tiny creatures were again observed by other physicians in Algeria and Italy. These were named *Plasmodium* in 1883 and it was suggested that *Plasmodium* was responsible for malaria disease.

In 1898 Grassi studied the life cycle of *Plasmodium* in *Anopheles* mosquito and discovered the relationship between man, mosquito and *Plasmodium*. With this discovery the facts about Biology of malaria were completely known.

The disease malaria was one of man's most important biological problems which, like other diseases was associated with a large number of biological problems.

Malaria is the disease that played havoc with human health, economy and even politics. It has killed a large number of people like any other fatal disease. In case of typical attack, victim of malaria feels very cold and chilly. His temperature may rise up to 106°F . He also suffers from headache and nausea.

After sometime the patient starts sweating and feels better but still weak and exhausted. The patient should be given antimalarial drugs, like Quinine, Poludrin or Chloroquine, at this time. If the patient is not given timely treatment he may again develop fever after some fixed interval. The attack of fever will follow on alternate days for many weeks. During the attack of malaria, the functioning of the various body parts of patient is greatly affected.

Many of his body parts do not function normally. The rate of heart beat and breathing may increase and the patient perspires profusely which lowers the temperature.

Life Cycle of Malarial Parasite: *Plasmodium*

Plasmodium is a parasite which completes its life cycle in two hosts, man and mosquito. When a female mosquito of genus *Anopheles* carrying *Plasmodium* in its saliva, bites a person, many parasites (**sporozoites**) are transmitted from the saliva of the mosquito into the blood of man (Fig. 1.1). They pass to the liver cells and multiply there for 12 days. Each sporozoite divides producing a large number of new cells called **merozoites**. These then enter the red blood cells and start

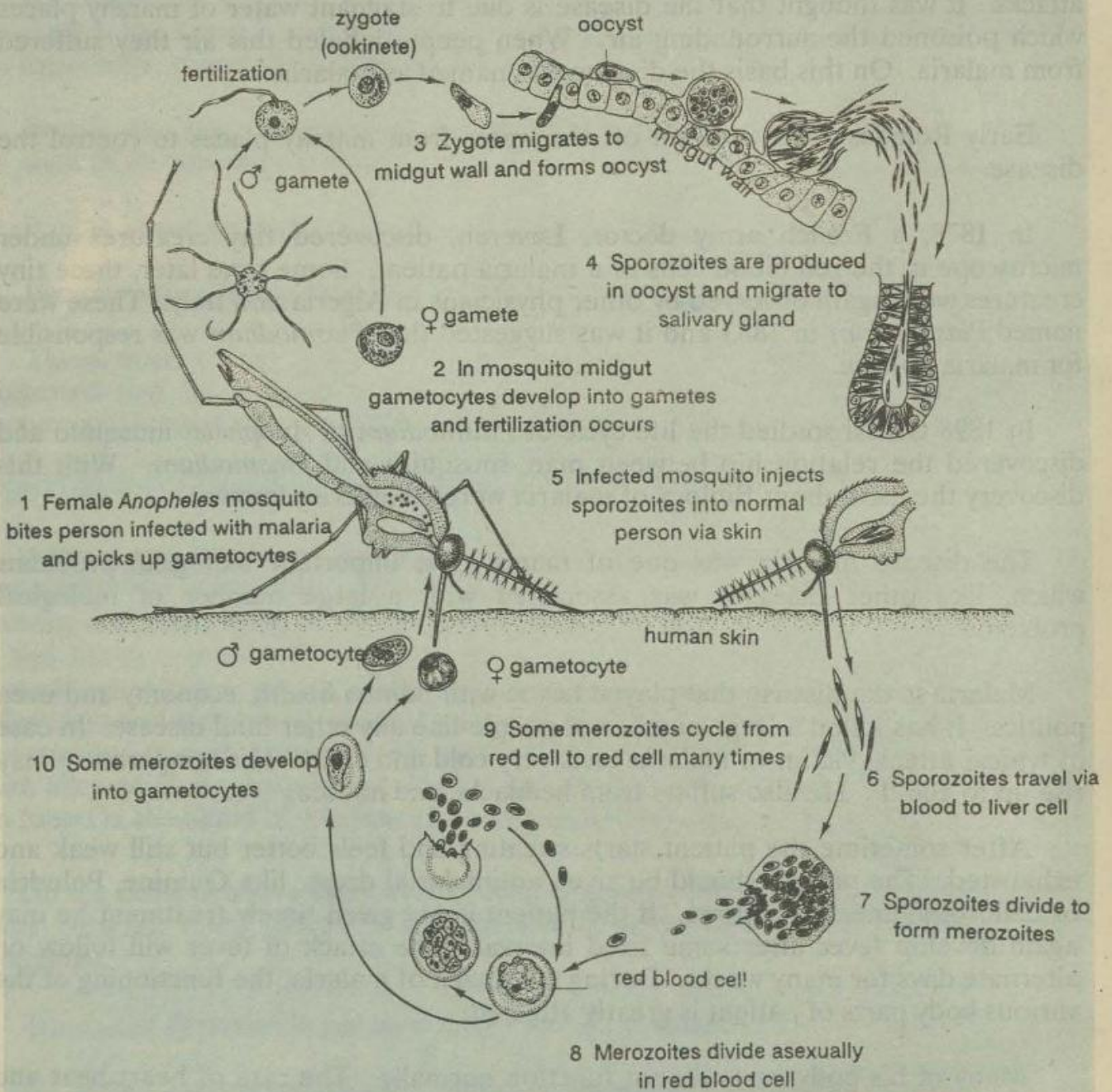


Fig 1.1 The life cycle of *Plasmodium*, the malarial parasite

reproducing there. When red blood cells burst, the merozoites are released into the blood of the patient. Each one of the merozoites released then enters another red blood cell. After a fixed interval, depending on the species of *Plasmodium*, a large number of these merozoites are released from red blood cells. After repeated cycles the number of *Plasmodium* increases rapidly and the patient shivers with chills and fever, which are usual symptoms of malaria.

After sometime the sexual phase of the parasite begins in the patient but is not completed until the **gametocytes** are taken into the gut of a mosquito. Here they develop into male and female gametes and unite to form zygote. The zygote bores its way into the stomach wall and develops a cyst around it. Inside the cyst many *sporozoites* are formed and eventually liberated through the salivary glands. When an infected mosquito bites a healthy person, the parasites (*sporozoites*) are injected into the blood system of the person who thus contracts malaria.

Discovery of Quinine

As the disease of malaria was being understood by biologists, a medicine which could cure malaria was discovered.

With the discovery of New World (America) many unknown plants were sent back to Europe to evaluate their medicinal importance. It was discovered that the bark of **cinchona** plant was found suitable for treating malaria. It was later discovered that cinchona bark contained quinine, a chemical substance which was effective against malaria.

Prevention of Malaria

With the study of the life history of the parasite (*plasmodium*) it became obvious that it is necessary to eliminate mosquitoes in order to eliminate malaria. Following measures should be adopted for prevention of malaria.

- 1) Mosquito's breeding places such as ponds, pools and marshes should be drained off.
- 2) A layer of kerosine oil on top of stagnant water kills larvae of mosquitoes.
- 3) Insecticides like DDT etc. can be used to kill mosquitoes.
- 4) Houses should be screened with wire gauze.
- 5) Antimalarial drugs such as Quinine, Poludrin, or Resochin should be taken.
- 6) Mosquito nets should be used during sleeping.
- 7) Application of oil to skin and use of repellents like coils etc. keeps the mosquitoes away.

QUESTIONS

1. Discuss the cause of malaria? How was it discovered? Describe the mechanism responsible for infecting human blood with malaria.
2. Explain the experiments conducted by Ross for investigation of various species of mosquitoes as a possible carrier of plasmodium?
3. Many people and many birds with malarial parasites in their blood do not show symptoms of the disease. Suggest a hypothesis to explain this and a way to test the deduction from it.
4. Which one is correct in the following given statements.
 - a. Malaria is an environmental problem.
 - b. Malaria is the disease of virus.
 - c. Malaria is related to bad air.
 - d. Malaria is found in marshy areas.

CELLULAR BASIS OF LIFE

2

DISCOVERY OF CELLS

The discovery of the cell is directly related with the invention of the microscope. This is because most of the cells are not visible to the naked eye. The first useful microscope was invented shortly before 1600. By about 1610, Galileo the Italian astronomer and physicist made a microscope and used it to observe very small animals. Robert Hooke, in 1665, also made a microscope and examined the cells of cork under it. Corks, used as bottle stoppers were made from the bark of cork oak. When he examined thin slices of these corks, he noticed small chambers in them with well-defined walls. Those chambers were called "cells" by Hooke (Fig 2.1). In 1824, a French botanist, Henri Dutrochet, confirmed Hooke's observations

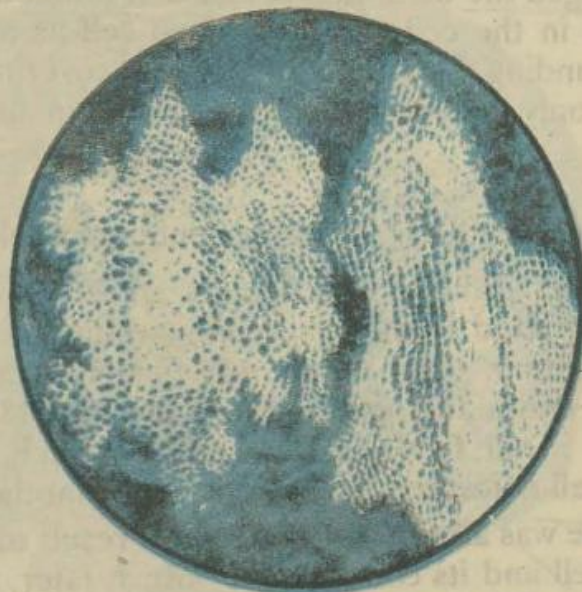


Fig. 2.1a The microscopic structure of a piece of cork. This illustration is from Hooke's *Micrographia*.



Fig. 2.1b Cork cells as seen by microscope under greater magnification.

on cells. He found that when plant material was boiled in nitric acid, it broke up into pieces. The tiny pieces, when examined under a microscope, were seen to contain box like units similar to those described by Hooke as cells. Robert Brown (1831) observed nucleus in the cells of orchids under the microscope. In 1839 a German zoologist Theodor Schwann looked at little bits of animals under his microscope. He observed nuclei in those cells but failed to see the cell walls. His observations thus changed the definition of cell. Schwann observed that nucleus was surrounded by a fluid in the cell. He described cell as a structure containing a nucleus, with its surrounding fluid and an outer thin covering or membrane. Outer thick wall was present only in plant cell and was absent in animal cell.

The Cell Theory

The cell theory is one of the most fundamental generalizations in biology. It states that all living beings - animals and plants are composed of cells and cell products. This theory resulted from numerous investigations that started at the beginning of the 19th century. The theory was finally formulated by a botanist named Schleiden (1838) and a zoologist named Schwann (1839). The cell theory has wide ranging effect in all fields of biological research. It was established immediately that every cell is formed by the division of another cell. The function of the organism as a whole was also recognised to be a result of the sum of activities and interactions of the cell and its components. Much later, with the progress of bio-chemistry, it was shown that there are fundamental similarities in the chemical composition and metabolic activities of all cells. The salient features of the cell theory in its present form are:

1. All organisms are composed of one or more cells.
2. All cells arise from pre-existing cells.
3. Cell is the basic structural as well as functional unit for all organisms.

Cell as a Unit of Structure and Function

A cell is a unit of structure and function in living organisms. In multicellular organisms there is a division of labour among cells. Different cells are specialized for different functions in animals e.g. muscle cells contract and relax, nerve cells transmit impulses, gland cells secrete, red blood cells carry oxygen and some stomach cells secrete gastric juice. Similarly in plants xylem cells conduct water and mineral salts from soil to the aerial parts of the plant. Phloem cells translocate food, sclerenchymatous cells give support to the plant, chlorenchymatous cells carry out photosynthesis and parenchymatous cells store surplus food. As they perform different functions they show great variation in shapes and sizes. Despite the structural and functional diversity, the plant cells have a common plan of organization.

Structure of a Generalized Cell

Structure of a cell can be studied under light microscope as well as electron microscope. The modern technology enables us to isolate various components of cells including its organelles by a process of cell fractionation and study their structure and function in detail. During cell fractionation the tissues are homogenized or disrupted with special instruments and the various parts of cells are separated by density gradient centrifugation. This separation is achieved by

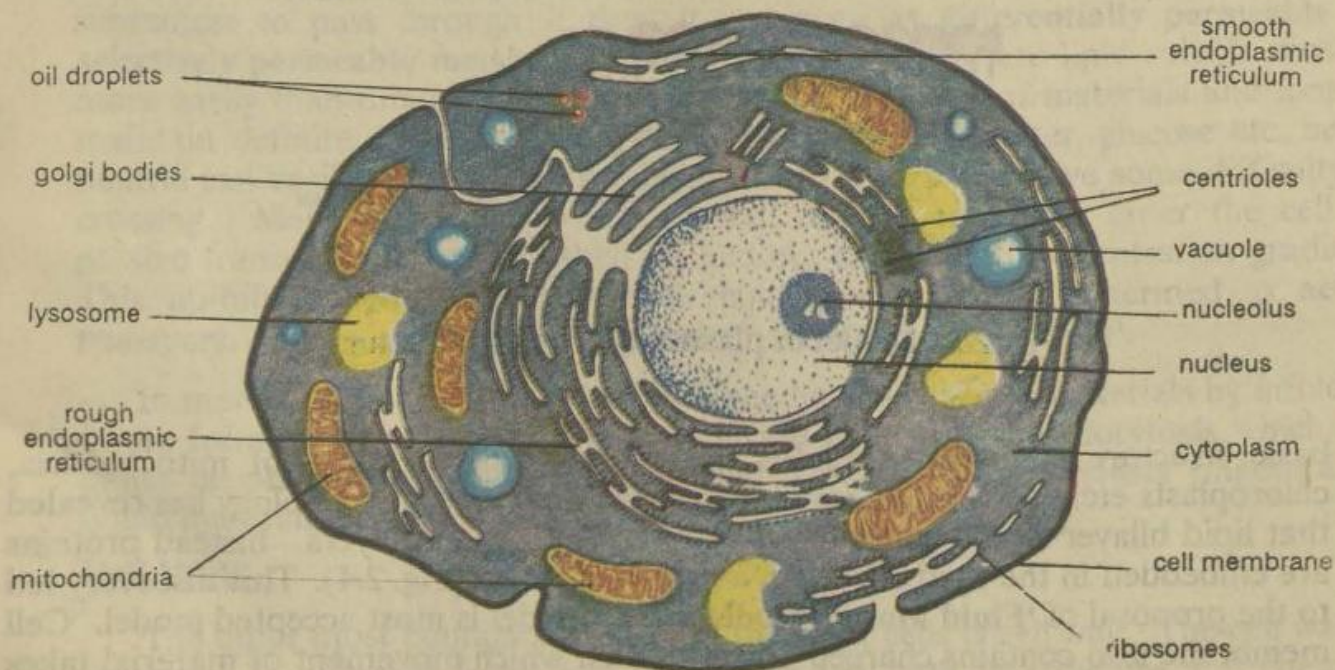


Fig. 2.2 An animal cell

spinning the homogenized or disrupted cells in a special medium in a centrifuge at medium speed. The various cellular parts separate out in different layers depending upon their size and weight, and density of the medium.

A cell (Fig 2.2) consists of the following basic components:

1. Plasma membrane; also a cell wall in plant cell.
2. Cytoplasm; containing cell organelles.
3. Nucleus; nuclear material.

Plasma Membrane

Plasma membrane, also known as cell membrane, is the outermost layer in the animal cell but lies beneath the cell wall in plant cell. It is thin, delicate, elastic and capable of limited self repair. It also provides mechanical support and external form to the protoplasm.

Cell membrane is chemically composed of lipids and proteins: 60-80% are proteins while 20-40% are lipids. In addition there is a small quantity of carbohydrate.

Many biologists contributed in describing the arrangement of lipids and proteins in cell membrane. Generally it was believed that plasma membrane is composed of lipid bilayer sandwiched between two protein layers (Fig. 2.3). This

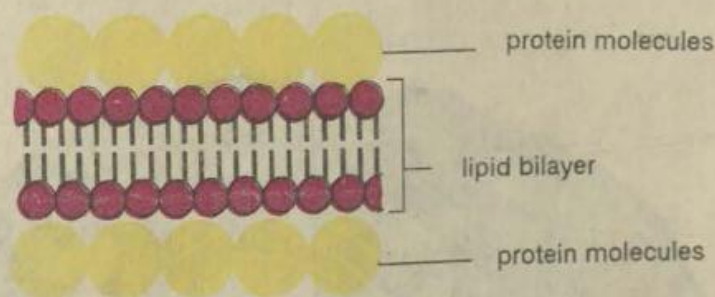


Fig. 2.3 Model of plasma membrane structure.

basic structure is found in all the membranes such as those of mitochondria, chloroplasts etc, and is called **unit membrane**. The modern technology has revealed that lipid bilayer is not sandwiched between two protein layers. Instead proteins are embedded in the lipid bilayer in a mosaic manner (Fig. 2.4). This discovery led to the proposal of '**Fluid Mosaic Model**'. This model is most accepted model. Cell membrane also contains charged pores through which movement of material takes place both by active and passive transport.

Transport of materials is one of the vital roles it plays for the cell. It offers a

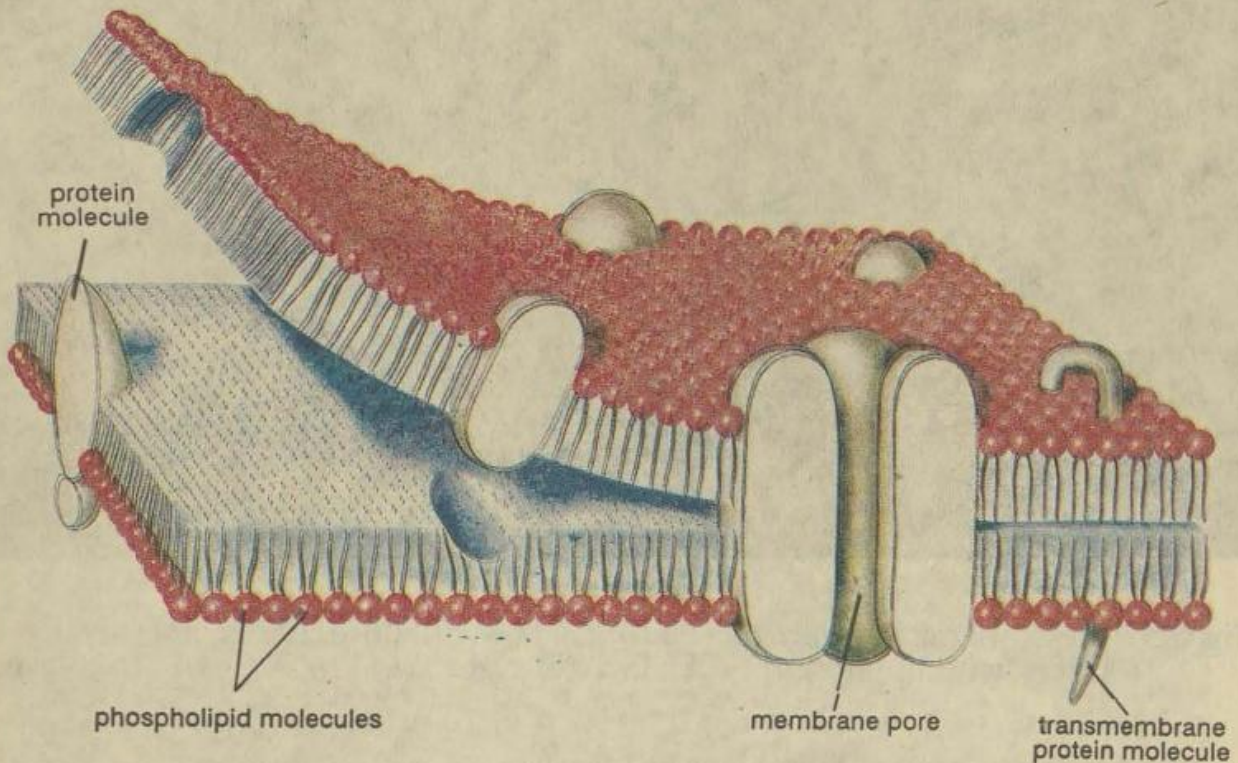


Fig. 2.4 Fluid mosaic model of plasma membrane. Protein molecules are dispersed within the lipid bilayer.

barrier between the cell contents and their environment, allowing only selective substances to pass through it; thus it is known as **differentially permeable or selectively permeable membrane**. The substances which are lipid soluble cross it more easily than others. Therefore, it regulates the flow of materials and ions to maintain definite gradient. Many small gas molecules, water, glucose etc. being neutral can easily cross while ions, being charged particles, have some difficulty in crossing. Many substances which are not needed constantly enter the cell by passive transport. These are then pushed out against the concentration gradient. This up-hill movement of materials requires energy and is termed as **active transport**. The energy used for this movement is provided by ATP.

In many animal cells the cell membrane helps to take in materials by infolding in the form of vacuoles. This type of intake is termed as **endocytosis** which can either be **phagocytosis** (ingestion of solid material) or **pinocytosis** (ingestion of liquid material).

Cell Wall

The outer most boundary in most of the plant cells is cell wall. The cell wall of plant cell is different from that of prokaryotes, both in structure and chemical composition. It is secreted by the protoplasm of the cell. Its thickness varies in different cells of the plant. It is composed of three main layers: primary wall,



Fig. 2.5 Electron micrograph of cell wall. The cellulose fibres are arranged in layers, with the fibres of each layer at right angle to those of other layers.

secondary wall and the middle lamella. The middle lamella is first to be formed in between the primary walls of the neighbouring cells (Fig. 2.5). The primary wall is composed of cellulose with some deposition of pectin and lignin. Cellulose molecules are arranged in a criss cross arrangement. The primary wall is a true wall and develops in newly growing cells. The secondary wall is formed on its inner surface and is comparatively thick and rigid. Chemically it is composed of inorganic salts, silica, waxes and cutin etc.

Cell wall is very important. It provides a definite shape to the cell and makes it rigid. It does not act as a barrier to the materials passing through it.

Cytoplasm

Inner to the cell membrane lies cytoplasm which contains many organelles. The living contents of the eukaryotic cells are divided into nucleus and cytoplasm, the two collectively form protoplasm.

Cytoplasm consists of an aqueous ground substance containing a variety of cell organelles and other inclusions such as insoluble wastes and storage products. The soluble part of the cytoplasm is called **cytosol**. It forms the ground substance of the cytoplasm. Chemically it is about 90% water and forms a solution containing all the fundamental molecules of life. Some of these are in ionic forms. Small molecules form true solutions and some large molecule form colloidal solutions. Colloidal solution may be sol (non-viscous) or gel (viscous).

The most important function of the cytoplasm is to act as a store house of vital chemicals. It is also a site of certain metabolic pathways (e.g. Glycolysis).

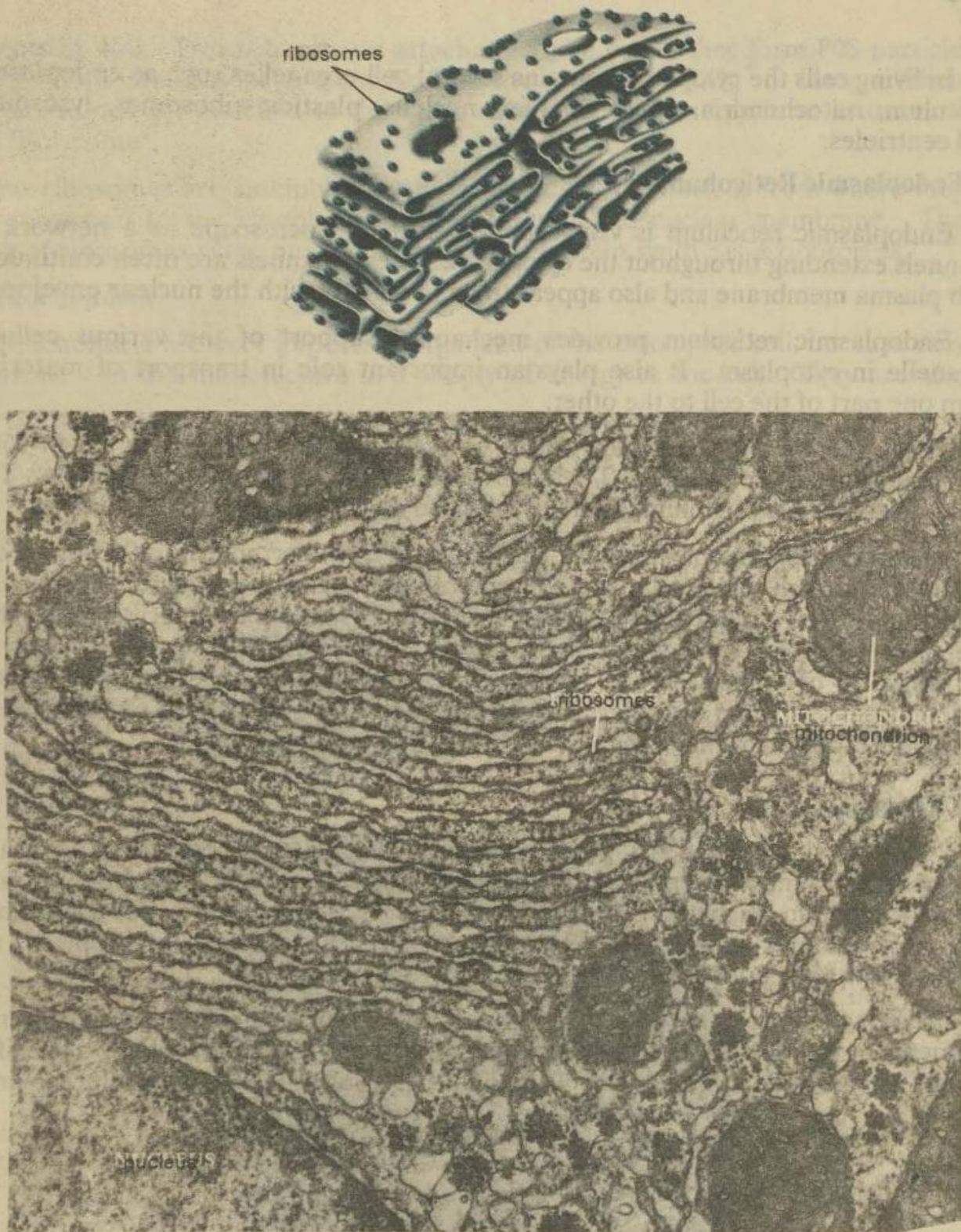


Fig. 2.6 Rough endoplasmic reticulum. In the drawing above you can see that the ribosomes (black dots) are associated with only one side of the rough ER; the other side bounds a separate compartment within the cell, into which the ribosomes extrude newly made proteins destined for secretion. The electron micrograph is of a rat liver cell, rich in ER-associated ribosomes. The rough ER is the large striated region in the center of the photograph.

In living cells the cytoplasm contains several cell organelles such as endoplasmic reticulum, mitochondria, Golgi complex, nucleus, plastids, ribosomes, lysosomes and centrioles.

(a) Endoplasmic Reticulum

Endoplasmic reticulum is visible under electron microscope as a network of channels extending throughout the cytoplasm. These channels are often continuous with plasma membrane and also appear to be in contact with the nuclear envelop.

Endoplasmic reticulum provides mechanical support of the various cellular organelle in cytoplasm. It also plays an important role in transport of materials from one part of the cell to the other.

There are two morphological forms of endoplasmic reticulum, a rough form with attached ribosomes (Fig. 2.6) and a smooth form without ribosomes. The rough endoplasmic reticulum (RER) is involved in the synthesis of proteins.

After synthesis the proteins are either stored in the cytoplasm or exported out of the cell through these channels. The smooth endoplasmic reticulum (SER) helps in metabolism of a number of different types of molecules particularly lipids. They also help to detoxify the harmful drugs. In some cells SER is responsible for transmission of impulses, e.g. muscle cells, nerve cells. In addition, smooth endoplasmic reticulum also plays an important role in transport of materials from one part of the cell to the other.

(b) Ribosomes

Cells contain many tiny granular structures known as ribosomes. They are composed of almost an equal amount of RNA and protein ; hence they are ribonucleoprotein particles. The RNA present in ribosome is called ribosomal RNA. Ribosomes exist in two forms; either freely dispersed in cytoplasm or attached with the endoplasmic reticulum as tiny granules.

Each eukaryotic ribosome consists of two subunits. The larger subunit sediments at 60S (S = Svedberg unit which specifies sedimentation rate of a specific particle or molecule in a medium during ultracentrifugation) while smaller subunit

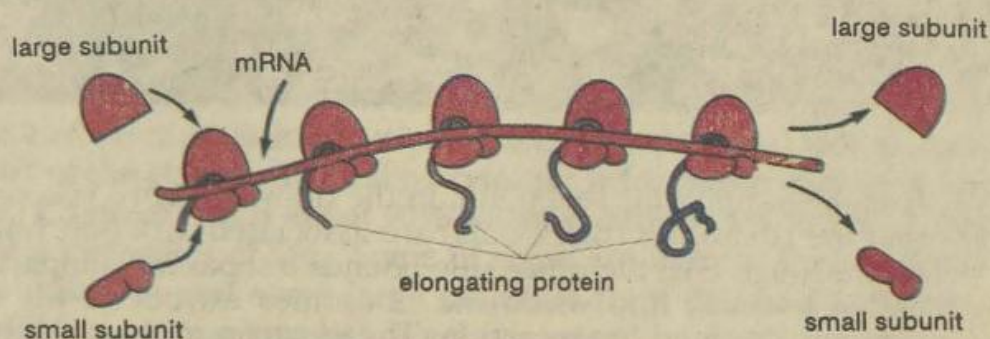


Fig 2.7 Two ribosomal subunits – one small, one large – attach to one end of an mRNA template.

sediments at 40S. Two subunits on attachment with each other form 80S particle (Fig. 2.7). This attachment is controlled by the presence of Mg^{++} ions. When many ribosomes get attached to the same stretch of mRNA they form a structure called "Polysome".

New ribosomes are assembled in the nucleolus of the nucleus from where they are transported to the cytoplasm via the pores in the nuclear membrane. The factory of ribosomes is the nucleolus and that of protein synthesis is ribosomes.

(c) Mitochondria

Mitochondria are very important organelle of the eukaryotic cell, because they are involved in the manufacture and supply of energy to the cell. They are also

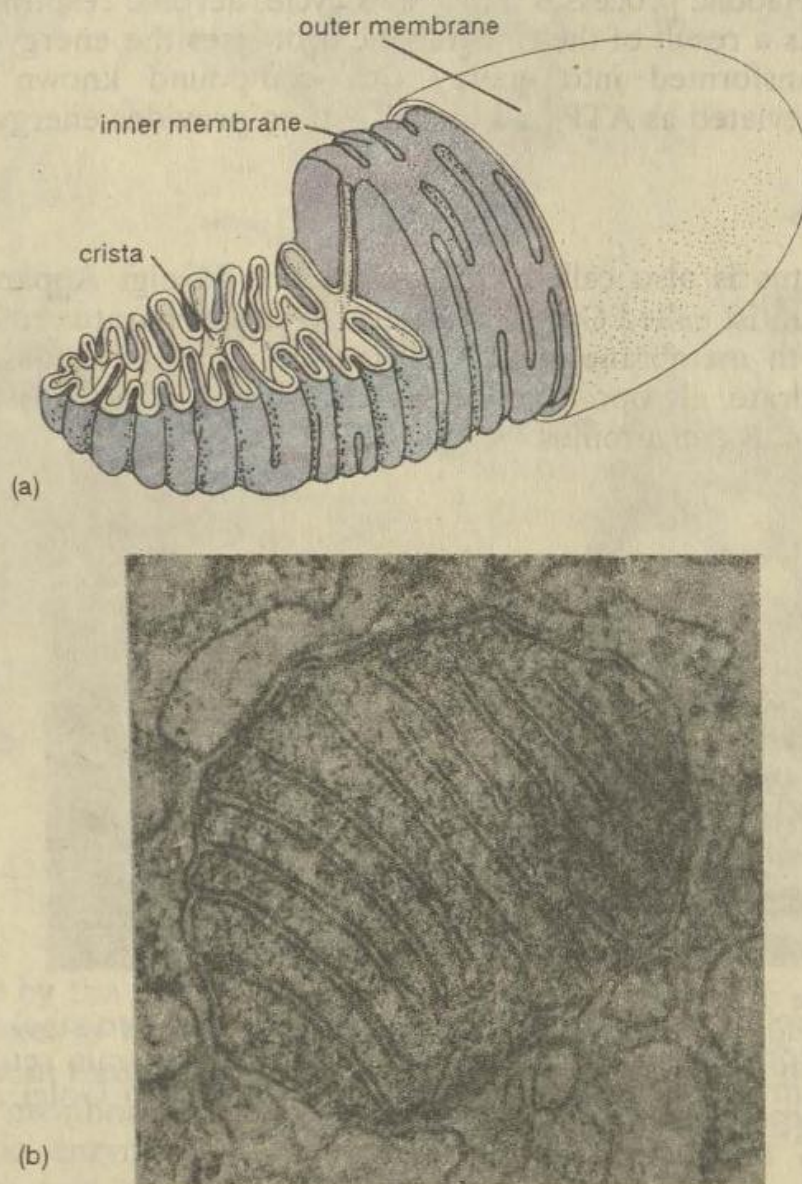


Fig. 2.8 Mitochondrion: cellular powerhouse.

(a) An artist's depiction shows the cristae of the inner membrane in three dimensions. The inner matrix that bathes the cristae contains DNA, ribosomes, and many kinds of enzymes. (b) An electron micrograph reveals the membranous nature of the cristae, magnified about 54,000 times.

known as power houses of the cell. Under compound microscope they appear to be vesicles, rods or filaments. Under electron microscope, they show a complex morphology. Although their number, shape and internal structure vary tremendously, a typical mitochondrion is bound by two membranes (Fig. 2.8), the outer membrane is smooth, while the inner membrane forms infolding into the inner chamber or mitochondrial matrix. These infoldings are called **cristae**. The mitochondrial membrane are similar in structure to other membranes. Detailed studies have shown that mitochondria also contains some DNA and ribosomes. The presence of ribosomes and DNA indicate that some proteins are also synthesized in it. It is self replicating organelle. Mitochondrial matrix contains in it a large number of enzymes, coenzymes and organic and inorganic salts which help in several vital metabolic processes like kreb's cycle, aerobic respiration, fatty acid metabolism etc. As a result of these metabolic processes the energy present in the food stuff is transformed into energy rich compound known as **adenosine triphosphate** abbreviated as ATP and the ATP then provides energy to the cell on demand.

(d) Golgi Apparatus

Golgi Apparatus is also called Golgi Complex. Golgi Apparatus has been named after a scientist called Golgi. The term Golgi Apparatus refers collectively to a set of smooth membranes that are stacked into flattened sacs containing proteins, carbohydrate, glycoprotein and specific enzymes (Fig. 2.9). In plants these are also referred to as dictyosomes.



Fig. 2.9 Golgi complex: packaging center for the cell. The two stacks of flattened vesicles represent Golgi complexes. Rough endoplasmic reticulum is also visible from where secretory products are shifted to Golgi apparatus for processing and packing as secretory granules.

Golgi Apparatus is concerned with cell secretions. Secretions are products formed within the cell on ribosome and then passed to the outside through endoplasmic reticulum and Golgi Apparatus. The secretions are converted into finished product and are packed inside membrane, before exporting it. For example in mammals, the pancreas secretes granules containing enzyme that help in

digestion. The Golgi body have role in formation of these granules. In plants, Golgi apparatus is involved in the synthesis of cell wall.

(e) Lysosomes

Lysosomes were isolated as separate components for the first time by De Duve (1949). Lysosomes (Lyso = splitting; soma = body) are found in most eukaryotic cells (Fig. 2.10). Any foreign object that gains entry into the cell is immediately



Fig. 2.10 Lysosomes (L) are digestive organelles within many eukaryotic cells. These lysosomes are within the cytoplasm of mouse kidney cells.

engulfed by the lysosomes and is completely broken into simple digestible pieces. The process is known as **phagocytosis** (eating process of a cell). They are most abundant in those animal cells which exhibit phagocytic activity. They are bound by a single membrane and are simple sacs rich in acid phosphates and several other hydrolytic enzymes. These enzymes are synthesized on rough endoplasmic reticulum and are further processed in the Golgi apparatus. The processed enzymes are budded off as Golgi vesicles and are called as **primary lysosomes** (Fig 2.11)

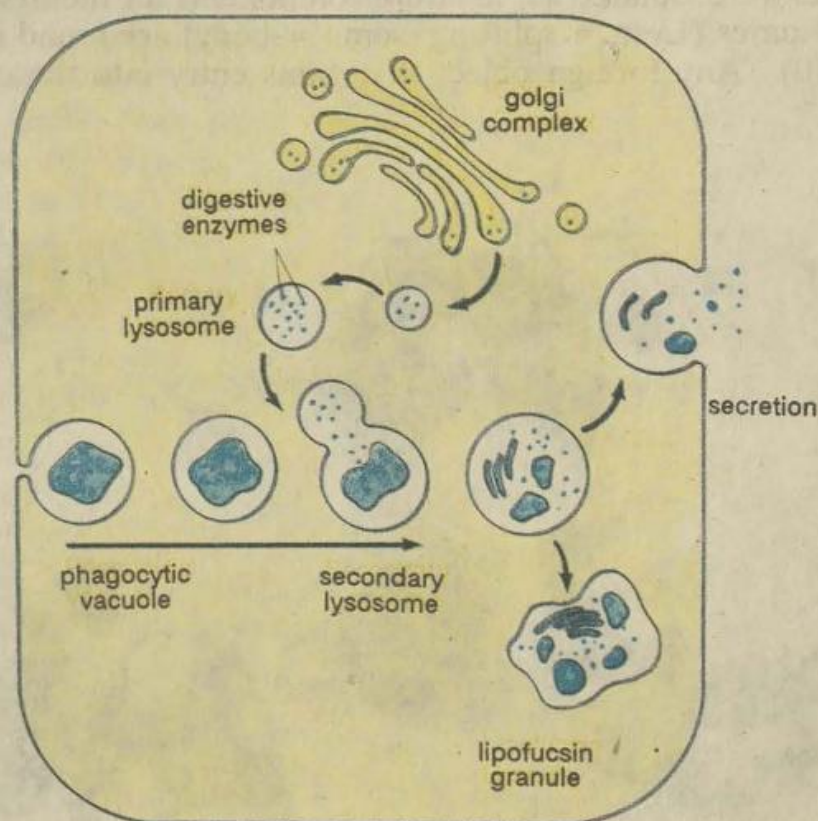


Fig. 2.11 Lysosome life history. Lysosomes arise from the Golgi complex and fuse with vacuoles that have engulfed some foreign material. These fused structures persist for a varying length of time and then discharge their wastes or give rise to a very long-lived lipofuscin granule.

Lysosomes contain those enzymes which can digest the phagocytosed food particles. They are also involved in the autophagy (self eating). During this process some parts of the cell are digested resulting in the degeneration of the cell. Lysosomes also release enzymes for extra cellular digestion.

(f) Centriole

Animal cells and the cells of some micro organisms and lower plants contain two centrioles located near the exterior surface of the nucleus. In cross section each centriole consists of a cylindrical array of 9 microtubules. However, each of the 9 microtubules is further composed of three tubules (Fig. 2.12). The two centrioles are usually placed at right angle to each other. Just before a cell divides, its centrioles duplicate and one pair migrates to the opposite side of the nucleus. The spindle then forms between them. They are absent in higher plants.

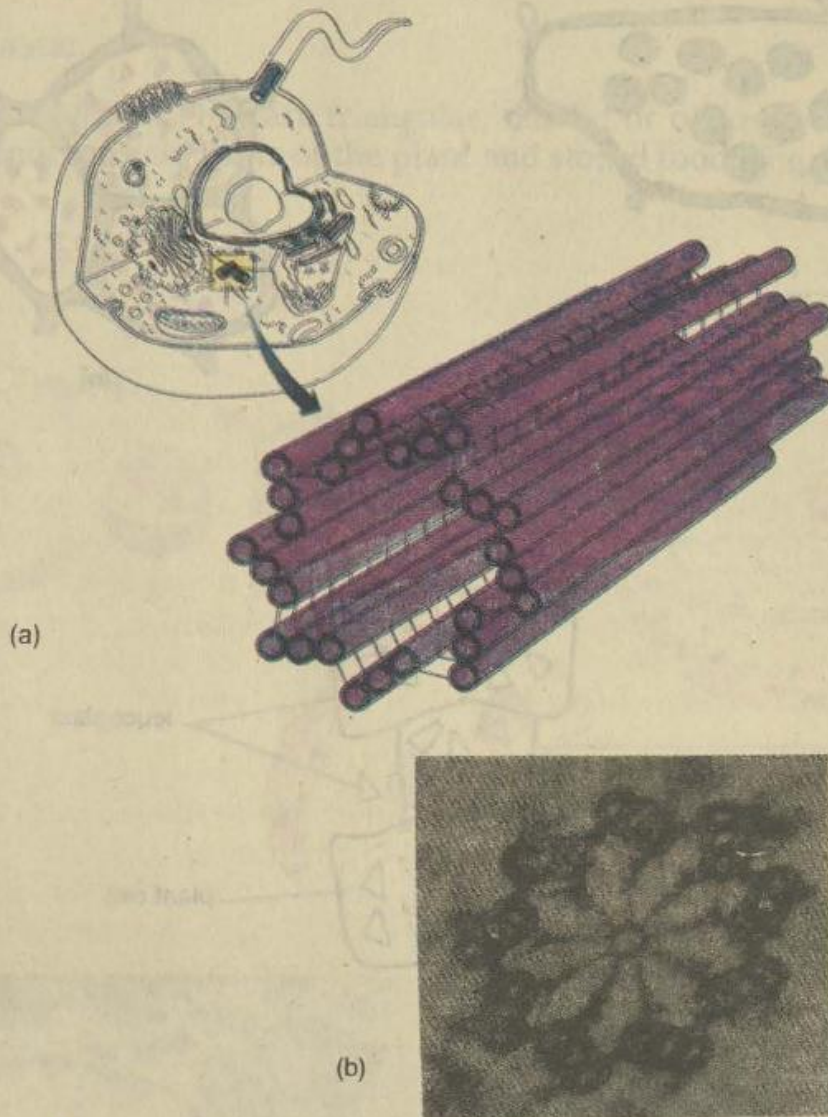


Fig. 2.12 Centrioles.

- (a) Centrioles are made up of nine microtubule triplets, (nine atoms of three microtubules each) (b) This electron micrograph, magnified about 160,000 times, shows a centriole in cross section. Spindle microtubules originate from centrioles. Each time a eukaryotic cell divides, its centrioles are duplicated so that each daughter cell receives a pair. The spindle moves the chromosomes during cell division.

(g) Plastids

Membrane bounded pigment containing bodies present in the cells are called as plastids. Plastids are present in plant cells only.

There are three main types of plastids.

(i) Chloroplasts:

The chloroplasts are organelles specializing in photosynthesis. They are green in colour. They are double membrane structures that are commonly oval or disc

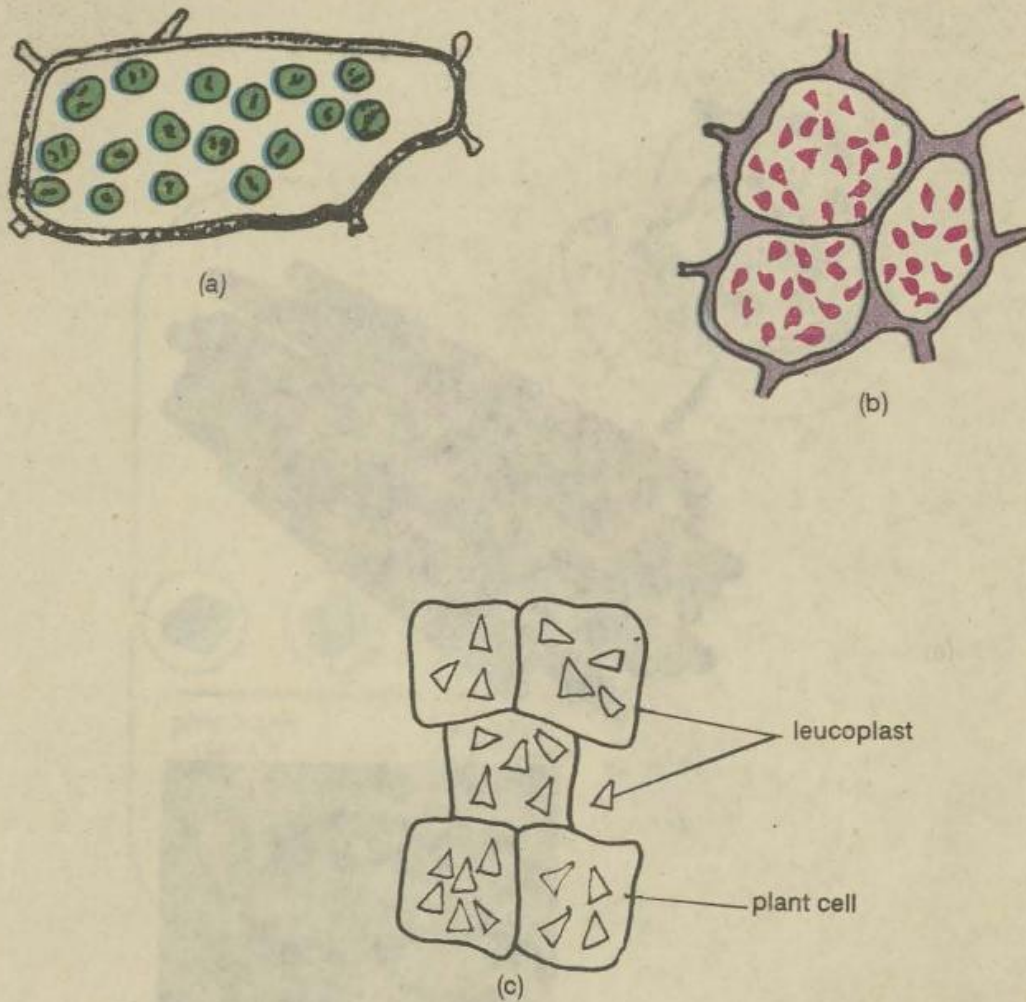


Fig. 2.13 a. Chloroplasts from the leaf cell of a moss.

b. Chromoplasts

c. Leucoplasts with starch grains.

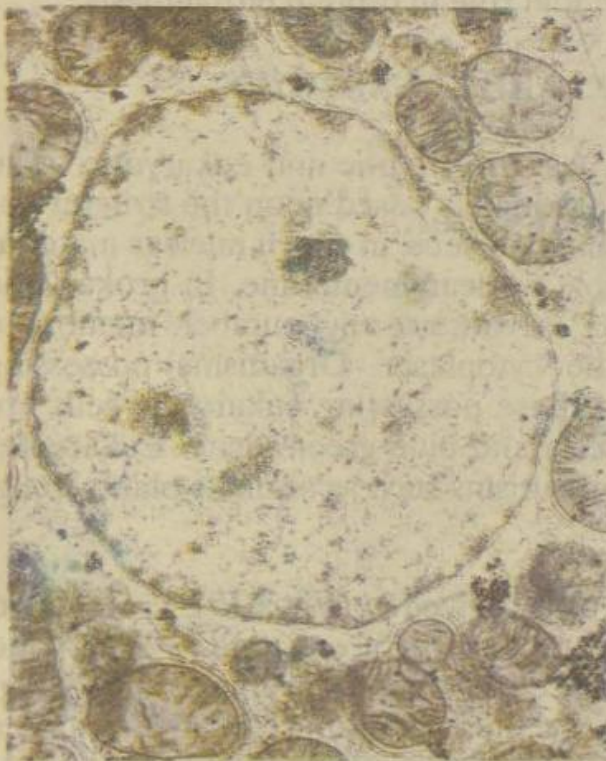
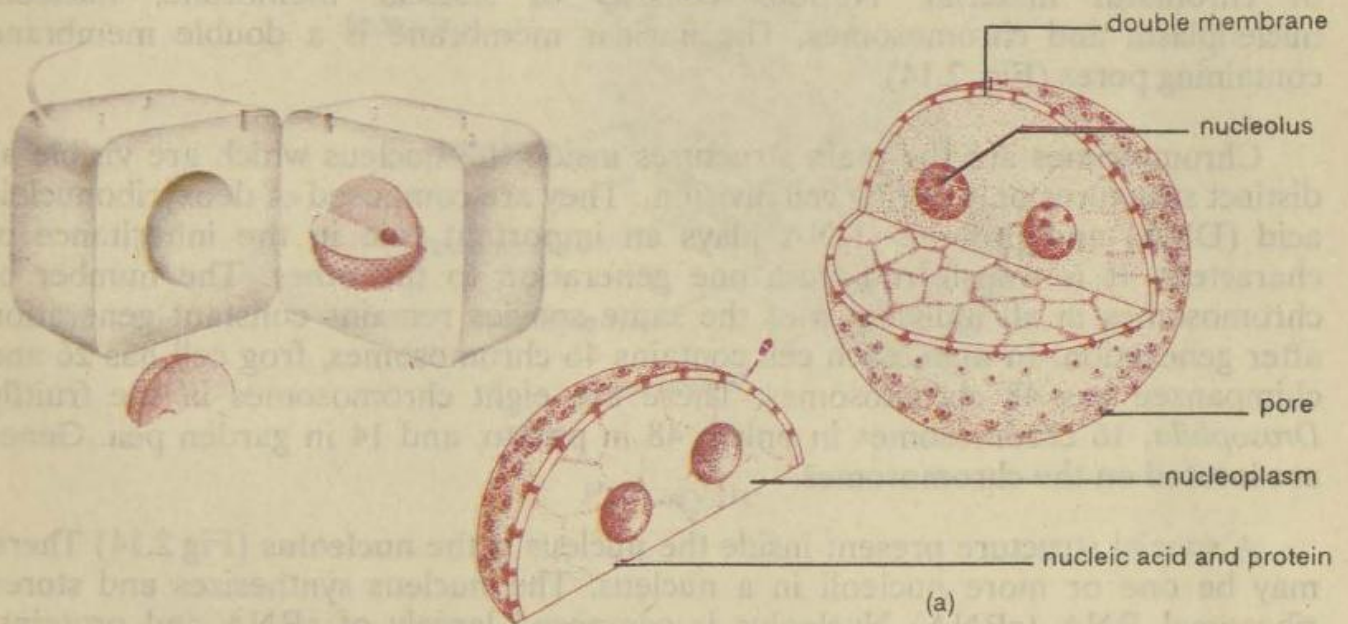
shaped (Fig. 2.13a). The inner chloroplast membrane gives rise to stacked membrane system that becomes suspended in the stroma (a semi-fluid matrix). Each membrane stack is called a **granum**. Membrane of the grana are sites where sunlight energy is trapped and where ATP is formed.

(ii) Chromoplasts:

They impart colours to the plants other than green. They are present in the petals of the flower and in the ripened fruit (Fig. 2.13b).

(iii) Leucoplasts:

They are colourless. They are triangular, tubular or of some other shape. They are found in underground parts of the plant and stored food (Fig. 2.13c).



(b)



(c)

Fig. 2.14 The nucleus. (a) Reconstruction. (b) As revealed by the electron microscope. (c) Detail showing nuclear pores.

Nucleus

Nucleus is a prominent structure within the cell. It may be irregular or spherical in shape. It controls the life and activities of the cell. In plant cell, the nucleus lies close to the cell membrane as there is a large central vacuole and the nucleus is pushed to one side. During interphase the chromosomes are in the shape of chromatin material. Nucleus consists of nuclear membrane, nucleoli, nucleoplasm and chromosomes. The nuclear membrane is a double membrane containing pores (Fig. 2.14).

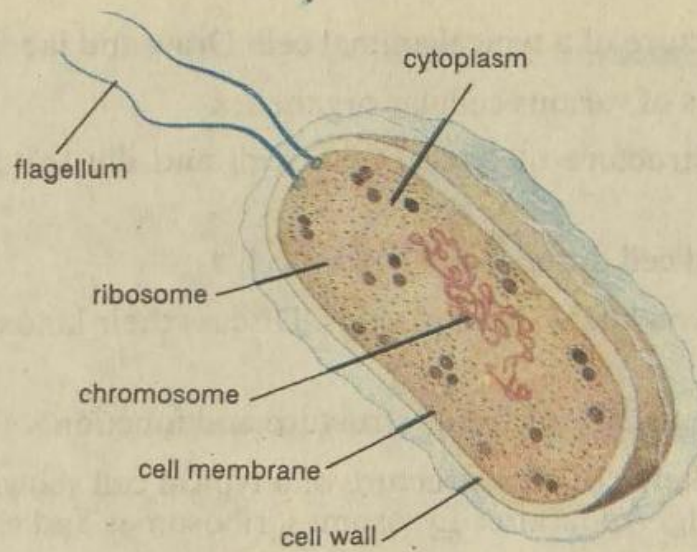
Chromosomes are the main structures inside the nucleus which are visible as distinct structures only during cell division. They are composed of deoxyribonucleic acid (DNA) and proteins. DNA plays an important role in the inheritance of characters. It is transferred from one generation to the other. The number of chromosomes in all individuals of the same species remains constant generation after generation. In man, each cell contains 46 chromosomes, frog cell has 26 and chimpanzee has 48 chromosomes. There are eight chromosomes in the fruitfly *Drosophila*, 16 chromosomes in onion, 48 in potato, and 14 in garden pea. Genes are located on the chromosomes.

A special structure present inside the nucleus is the **nucleolus** (Fig 2.14) There may be one or more nucleoli in a nucleus. The nucleus synthesizes and stores ribosomal RNA (rRNA). Nucleolus is composed largely of rRNA and proteins. There are three kinds of RNAs, **messenger RNA (mRNA)** **transfer RNA (tRNA)** and **ribosomal RNA (rRNA)**. They play essential role in protein biosynthesis.

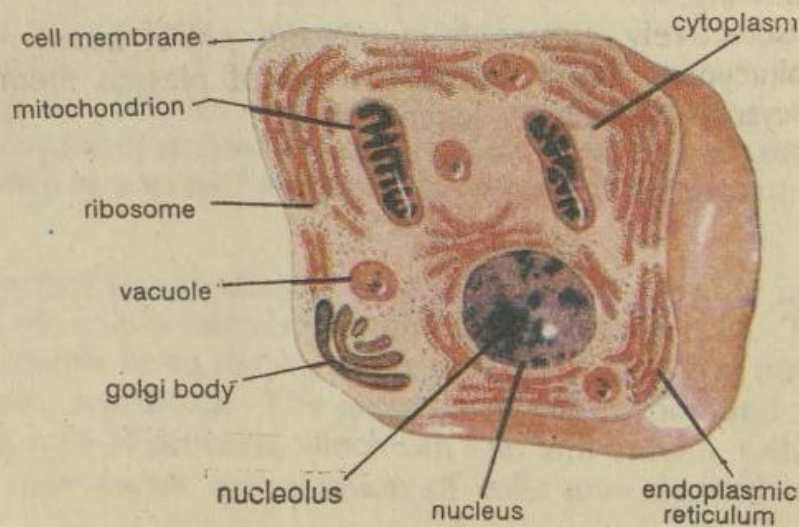
DIFFERENCES BETWEEN PROKARYOTES AND EUKARYOTES

Biologists have divided cells into two types: prokaryotic and eukaryotic. The differences between these two types of cells are mainly based upon the structure of their nuclei. Eukaryotes have a very well defined nucleus, in which nuclear material (chromosomes or DNA) is enclosed in double nuclear membrane. In prokaryotic cells, however the genetic material (DNA) is without any number membrane covering and is directly submerged in the cytoplasm. Organisms possessing prokaryotic cells are called **Prokaryotes** and those possessing eukaryotic cells are called **Eukaryotes**. Prokaryotes include bacteria and blue green algae. Eukaryotes include all other unicellular or multicellular organisms such as animals plants, fungi and protista.

A diagram of prokaryotic and eukaryotic cells is given in (Fig 2.15). Prokaryotic cells generally lack many of the membrane bounded structures found in eukaryotic cells. For example, mitochondria, endoplasmic reticulum, chloroplasts and Golgi apparatus are absent in prokaryotic cells. Since there is no nuclear membrane, a prokaryotic cell has no distinct nucleus and its DNA molecule is directly suspend in cytoplasm. Prokaryotes have small sized ribosomes 70S compared to eukaryotes 80S. In prokaryotes mitosis is missing and the cell divides by binary fission. Because of their simpler structure, it was widely accepted for a long time that prokaryotic



Prokaryote



Eukaryote

Fig 2.15 Difference between prokaryote and eukaryote cell.

cells represent a more primitive stage of evolution than eukaryotic cells. Perhaps the most distinctive feature of the prokaryotic cell is its cell wall, composed of polysaccharide chains bounded covalently to shorter chains of amino acids forming peptidoglycan or murein. The entire cell wall is often regarded as a single huge molecule or molecular complex called murein. The cell wall of plants is generally made up of cellulose and is differently structured than that of a bacterium.

QUESTIONS

1. Describe the structure of a typical animal cell. Draw and label different parts.
2. Describe functions of various cellular organelles.
3. a) Describe the structure of typical plant cell and illustrate it with a labelled diagram.
(d) How an animal cell differs from a plant cell ?
4. (a) Write all that you know about plastids. Discuss their kinds and their functions.
b) What is a nucleus ? Describe its structure and function.
5. Make a labelled sketch of ultrastructure of a typical cell showing a nucleus, mitochondria, Golgi Apparatus, Lysosomes, ribosomes and endoplasmic reticulum.
6. (a) Explain with the help of diagram the differences between prokaryotic and Eukaryotic cells.
(b) Differentiate between plant cell wall and bacterial cell wall.
7. Define the following:
Phagocytosis, selectively permeable membrane, power house of the cell, active transport, prokaryotes, Fluid Mosaic Model of plasma membrane, colloidal solution, endocytosis, autophagy, leucoplasts.

CHEMISTRY OF CELL

3

As discussed in the previous chapter, all organisms are composed of cells. A typical cell consists of three important components i.e. protoplasm, a nucleus and plasma membrane. Protoplasm is a translucent; somewhat viscous substance surrounded by plasma membrane, while nucleus lies inside the protoplasm. Protoplasm, for convenience of description, can be divided into nucleoplasm, which is present inside the nucleus and the cytoplasm, which is present between the nucleus and plasma membrane. Cytoplasm, consists of liquid matrix known as cytosol, in which several different types of organelles are suspended. Most of the cellular functions are due to special properties of cytoplasm. Movements of cells from one place to another, contractility, sensitivity to various stimuli such as touch, temperature, light, and cell division are largely due to cytoplasm, while the property of growth and reproduction is dependent upon nucleus and its content. Cell owes its structure and function to various biochemicals, which it is composed of.

The viscosity of protoplasm is comparable with that of glycerol or light machine oil. Protoplasm of plant cells is less viscous than that of animal cells. The property of viscosity mainly depends upon the water content besides several other chemical compounds and cellular organelles. The property of contraction and relaxation is attributable to special type of proteins, which can fold and unfold. Other functions such as streaming movements and division of cells also depend upon special proteins.

CHEMICAL COMPOSITION OF PROTOPLASM

Typically an animal and a bacterial cell consists of some chemicals as shown in table I.

Table 1: Approximate chemical composition of a typical bacterial and a typical mammalian cell.

Chemical components	% total cell weight	
	Bacterial cell	Mammalian cell
1. Water	70	70
2. Proteins	15	18
3. Carbohydrates	3	4
4. Lipids	2	3
5. DNA	1	0.25
6. RNA	6	1.1
7. Other organic molecules (Enzymes, hormones, metabolites)	2	2
8. Inorganic ions (Na^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , SO_4^{--} etc)	1	1

Some of these chemical compounds are described below.

1. Water

Water is the most abundant component in living cells. Its amount varies from 65% - 85%. Activities in the cell occur only due to the presence of water.

Water is the best solvent. More chemical substances dissolve in it than in any other liquid. The water thus makes possible those reactions to take place which would have been impossible if the substances had been dry. When substances dissolve in water, they react better. Many substances ionize when they are

dissolved in water, e.g., table salt ionizes into Na^+ and Cl^- ions. In ionized state substances react more readily. All the molecules in water solution go on moving from place to place and it results in the equal distribution of these molecules.

2. Proteins

Protein is the second most abundant component of cell and is the most abundant organic compound in the animal and plant cells. You will recall from chapter 2 that both the animal and plant cells are composed of membranes. These membranes are also known as lipo-protein membranes because they consist of lipids as well as proteins. Proteins, therefore, constitute major structural component of the cell. Besides that proteins perform different functions. Proteins catalyze biological reactions in the form of enzymes. Many hormones are composed of protein. Proteins take part in the structure of seeds and other plant parts. They also make the material which forms skin, muscles, hairs and nails in animals. Haemoglobin, the oxygen carrying substance in red blood cells, is also a protein. Proteins play a key role in the contraction of muscles, digestion of food and clotting of blood. They perform several other functions as well.

The proteins are made up of amino acids. Upto 20 different kinds of amino acids go into the formation of a protein molecule. An amino acid is an organic molecule containing at least one amino ($-\text{NH}_2$) and one carboxyl ($-\text{COOH}$) group bonded to the same carbon atom, also known as alpha carbon (Fig. 3.1).

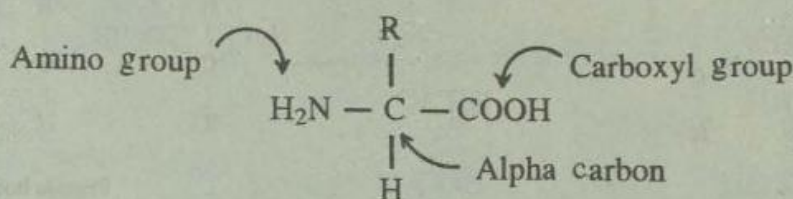


Fig. 3.1 A general formula of an amino acid.

The number of amino acids is variable in a protein molecule, and so is their arrangement. For example, insulin has 51 amino acids, which are arranged in two polypeptide chains, one of 21 amino acids and the other of 30 amino acids (Fig. 3.2). Haemoglobin is composed of four chains, two alpha and two beta chains. Each alpha chain contains 141 amino acids, while each beta chain contains 146 amino acids. Amino acids are linked to each other by a peptide bond which is formed by amino group of one amino acid and carboxyl group of an adjacent amino

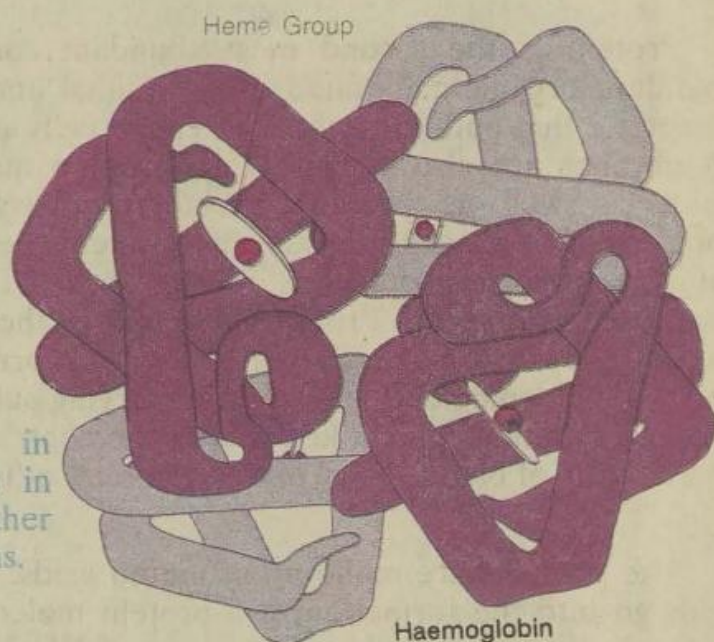
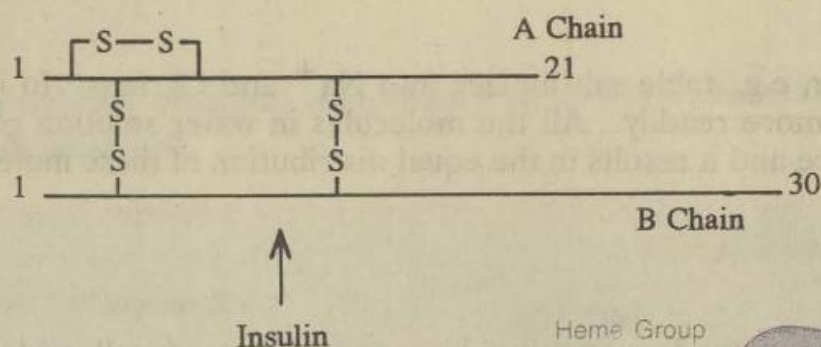


Fig. 3.2. Two polypeptide chains in insulin and four polypeptide chains in haemoglobin molecules are held together to form a respective functional proteins.

acid (Fig 3.3). A chain containing three amino acids is known as **dipeptide**, with six amino acids is known as **pentapeptide** and with many amino acids as **polypeptide**.

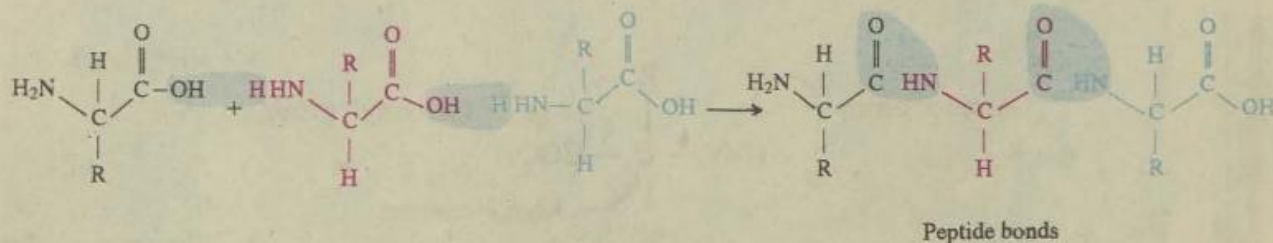


Fig. 3.3. Three amino acids join together to form dipeptide. Make a special note of peptide bonds.

Majority of protein molecules have from 300 to 3000 amino acids. The arrangement of amino acids in a protein molecule is highly specific for its proper functioning. If any amino acid is not at its proper place, the protein molecule fails to carry on its normal function. The best example of it is the sickle cell haemoglobin of human beings. In this case only one of the 574 amino acids do not occupy the normal place and haemoglobin fails to carry oxygen which leads to the death of the patient. The size of the protein molecule depends upon the kind and total number of amino acids making the molecule. The shape of the protein molecule depends upon the manner in which different peptide chains have been

connected. Some proteins are long, thin fibers, such as those of hair and silk. Some proteins are globular, e.g., haemoglobin. Some are cigar or sausage like.

In our body, there are hundreds of different kinds of protein molecules. Some of them are specific to human race and some are specific to the individual. So is the case in plant kingdom.

3. Carbohydrates

Carbohydrates are organic compounds consisting of carbon, hydrogen and oxygen present in all living organisms. Carbohydrates in combination with lipids and proteins constitute complex conjugated molecules (glycolipids, glycoprotein), which not only form part of membranes, but also constitute cell secretions. Carbohydrates can be divided into 3 major classes, namely **monosaccharides**, **oligosaccharides** and **polysaccharides**, which are briefly described below.

a. Monosaccharides

These are sweet in taste, are easily soluble in water, and cannot be hydrolyzed into simpler sugars. These sugars have a general formula $C_n(H_2O)_n$. They can be classified into **trioses**, **tetroses**, **pentoses**, **hexoses**, **heptoses**, **octoses** etc depending upon the number of carbon atoms present. Trioses have 3 carbons, tetroses 4 carbons, pentoses 5 carbons, hexoses 6 carbons, heptoses 7 carbons, octoses 8 carbons and so on. Glyceraldehyde (Fig 3.4) is one of the trioses and has general

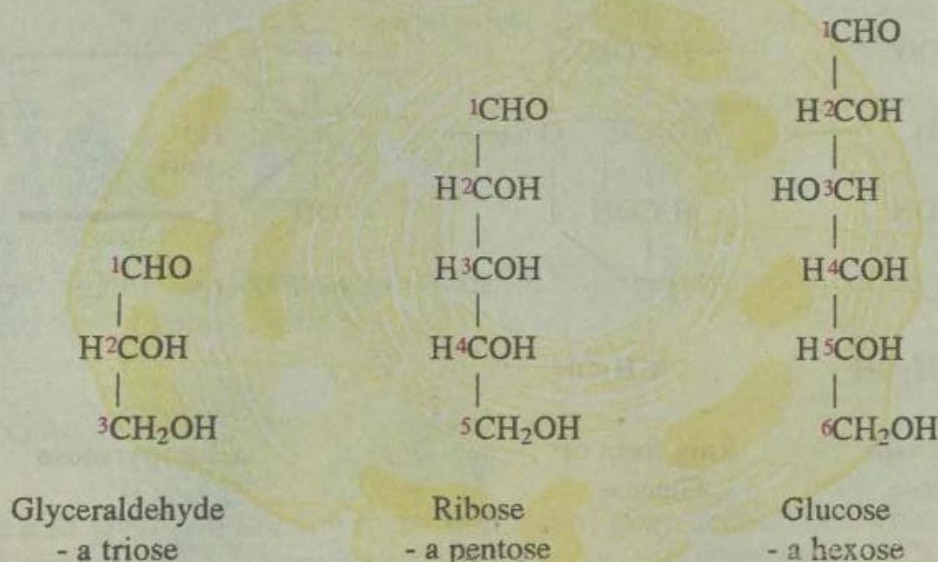


Fig. 3.4 Some monosaccharides.

formula $C_3H_6O_3$. Ribose sugar is one of the common pentoses with a chemical formula $C_5H_{10}O_5$ and is an important component of ribonucleic acid. Hexoses (chemical formula $C_6H_{12}O_6$) include much more common sugars such as glucose, fructose, mannose, galactose etc. Most of the monosaccharides form a ring structure when in solution. For example, ribose will form a ring known as ribofuranose and glucose will form glucopyranose (Fig. 3.5). Furan is a general term for 5 cornered ring, while pyran is used for 6 cornered ring.

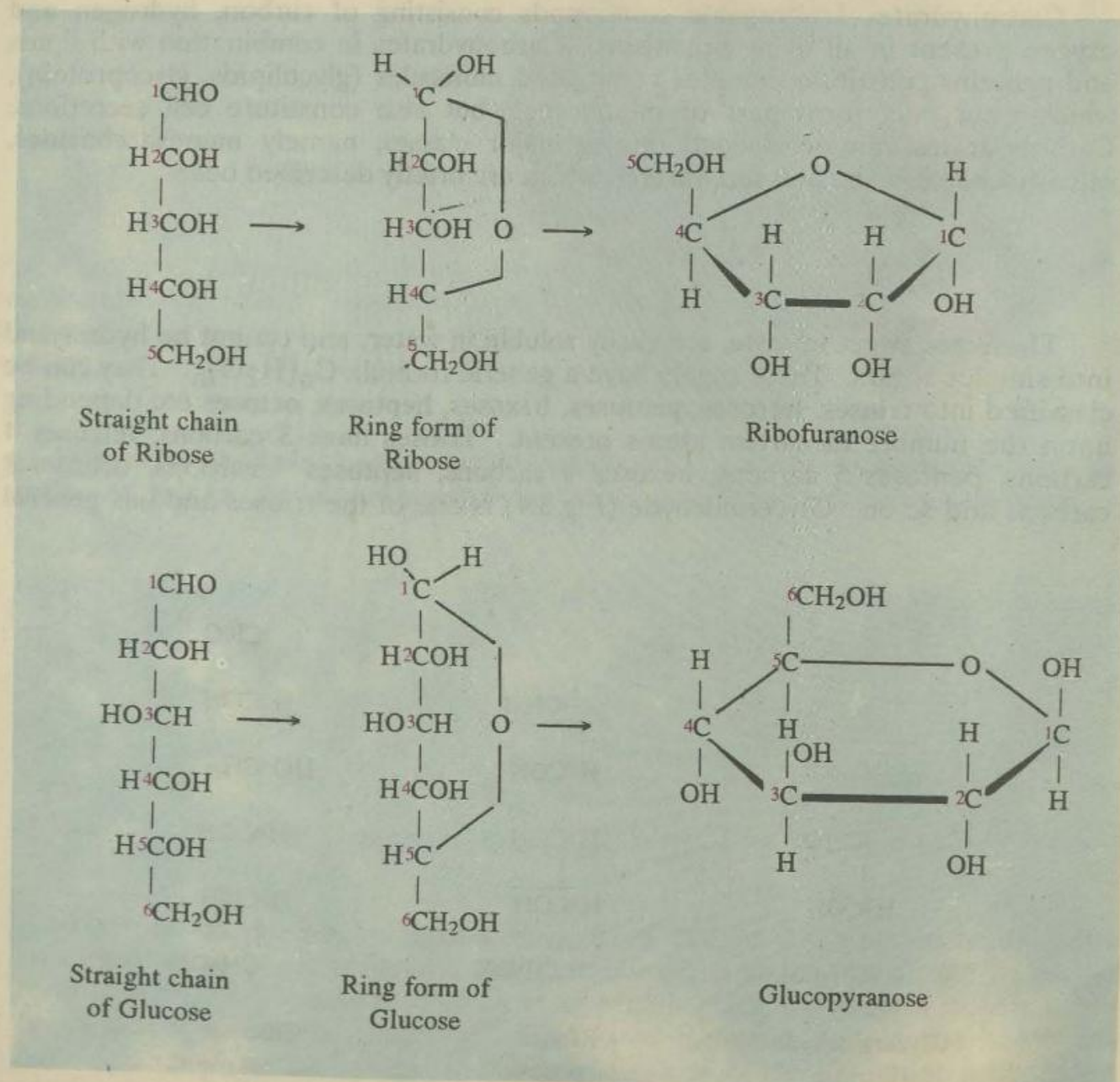


Fig. 3.5. Straight chain structure and ring structure of a ribose and glucose molecule.

b. Oligosaccharides

These sugars are comparatively less sweet in taste, and less soluble in water. On hydrolysis, oligosaccharides yield from two to ten monosaccharides. The ones yielding 2 monosaccharides are known as **disaccharides**, those yielding three are known as **trisaccharides** and so on. Lactose, maltose and sucrose are the important disaccharides in the living organisms (Fig. 3.6).

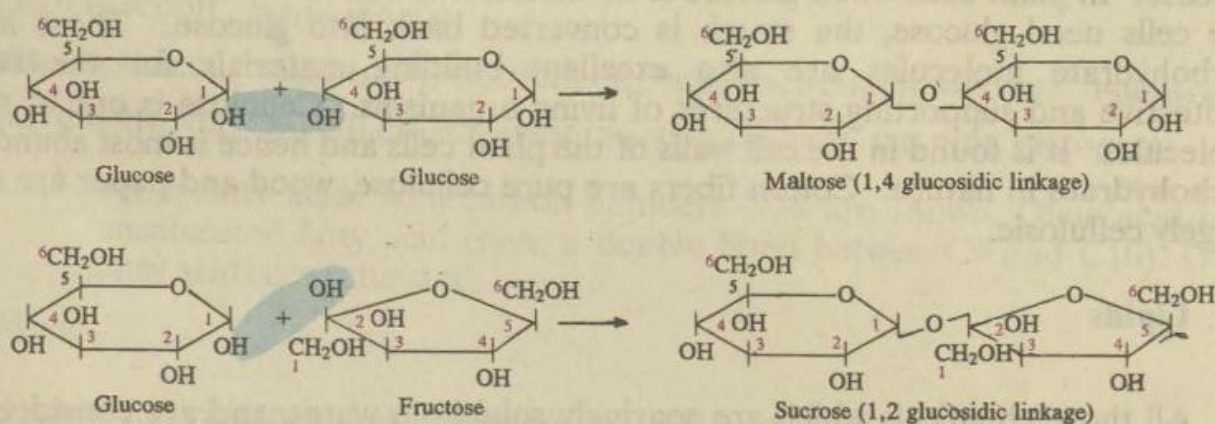
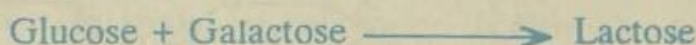


Fig. 3.6. A few disaccharides. Note carefully the glucosidic linkages between the two monosaccharide units.

c. Polysaccharides

Starch and glycogen are the most important polysaccharides which are stored in plant and animal cells, respectively, as reserve food material. They are usually branched (Fig. 3.7) and tasteless, and are insoluble in water. On hydrolysis, they yield glucose monomers.

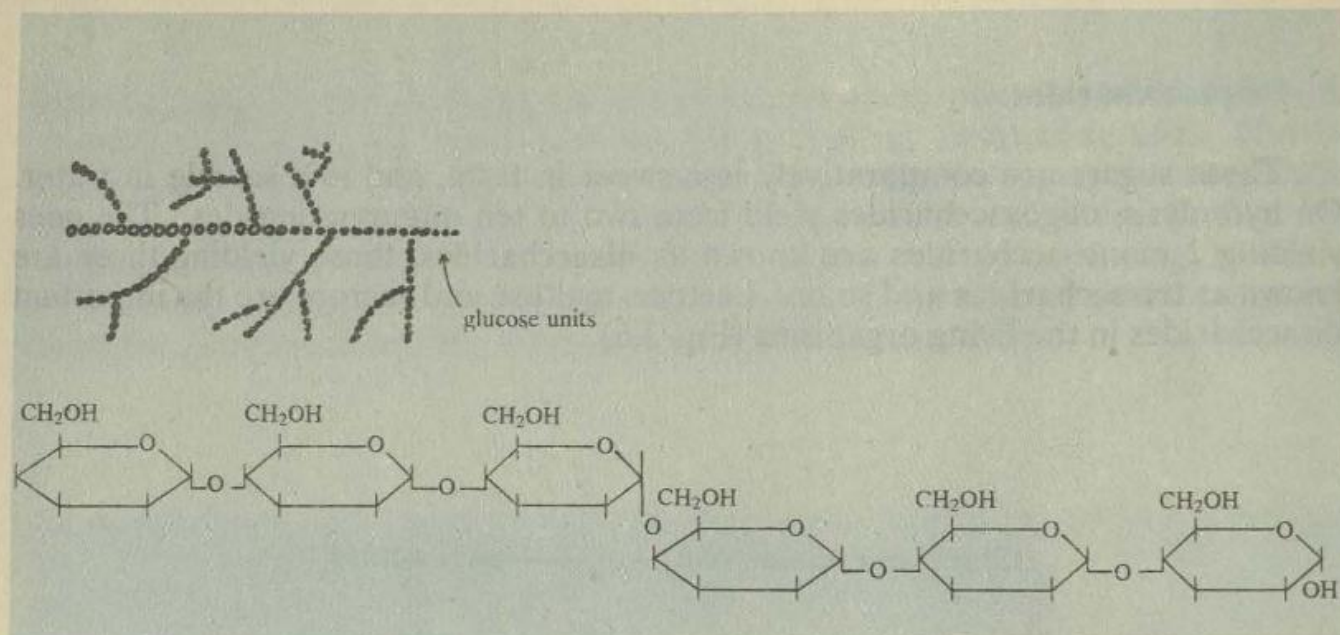


Fig. 3.7. Polysaccharides are polymers of monosaccharides. 1, 4 linkage is present between monomers, while 1, 6 linkage is visible at the branching point.

Polysaccharides act as storage molecules for the small carbohydrate units, like glucose. In plant cells when glucose is in excess, it is converted into starch. When the cells need glucose, the starch is converted back into glucose. These large carbohydrate molecules are also excellent building materials for the solid, protective and supporting structures of living organisms. Cellulose is one of such molecules. It is found in the cell walls of the plant cells and hence is most abundant carbohydrate in nature. Cotton fibers are pure cellulose, wood and paper are also largely cellulosic.

4. Lipids

All those chemicals which are sparingly soluble in water, and are considerably soluble in organic solvents are grouped under lipids. Lipids have been classified as acyl glycerols, waxes, phospholipids, sphingolipids, glycolipids and terpenoid - lipids including carotenoids and steroids. The structure of some of these lipids is given in fig. 3.8.

a. Acylglycerols

Acylglycerols are composed of glycerol and fatty acids (Fig. 3.8). The most widely spread acyl glycerol is triacyl glycerol, also called triglycerides or **neutral lipids**. Fatty acids are one of the most important components of triglycerides. Fatty acids contain even numbers (4-30) of carbon atoms in straight chain and may contain no double bond (saturated fatty acids) or upto 6 double bonds (unsaturated

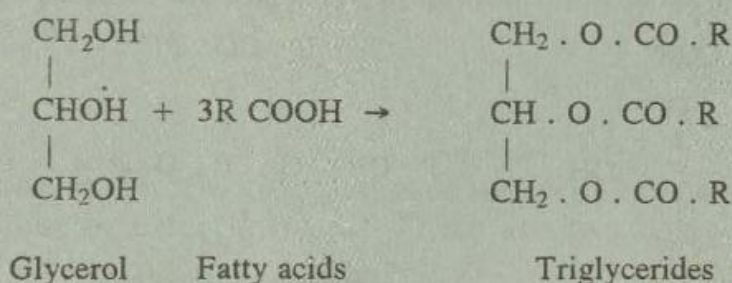


Fig. 3.8 Triacylglycerol is composed of glycerol and fatty acids.

fatty acids). In animals the fatty acids are straight chains (Fig. 3.9), while in plants these may be branched or ringed. Solubility of fatty acids in organic solvents and their melting points increase with increasing number of carbon atoms in chain. Palmitic acid (C_{16}) is much more soluble in organic solvent than butyric acid (C_4). The melting point of palmitic acid is 70°C as against -8°C for butyric acid.

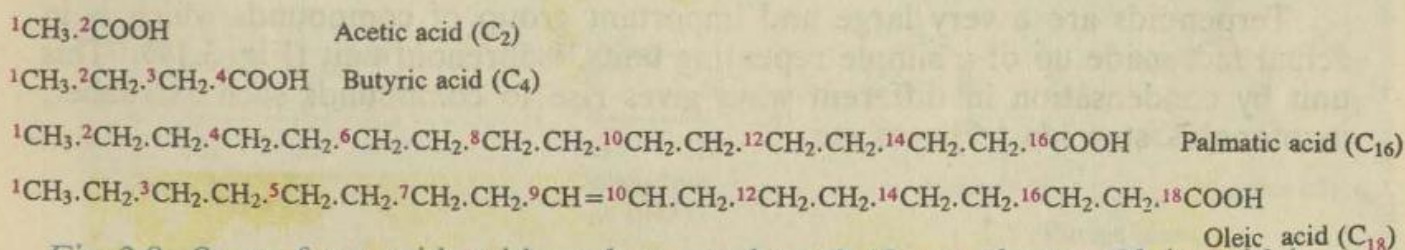


Fig. 3.9 Some fatty acids with carbon numbers 2-18 are shown. Oleic acid is an unsaturated fatty acid (note a double bond between C_9 and C_{10}). Other fatty acids are saturated.

b. Waxes

Waxes are widespread as protective coatings on fruits and leaves. Some insects also secrete wax. Chemically, waxes are mixtures of long chain alkanes (with odd number of carbons ranging from C_{25} to C_{35}) and alcohols, ketones, and esters of long chain fatty acids. Waxes protect plants from water loss and abrasive damage. They also provide water barrier for insects, birds and animals such as sheep.

c. Phospholipids

Phospholipids are derivatives of phosphatidic acid (Fig. 3.10), which are composed of glycerol, fatty acids and phosphorous. Nitrogenous bases such as choline, ethanolamine and serine are important components of phospholipids. They are widespread in bacteria, animal and plant cells and are frequently associated with membranes. Phosphatidylcholine is one of the common phospholipids.

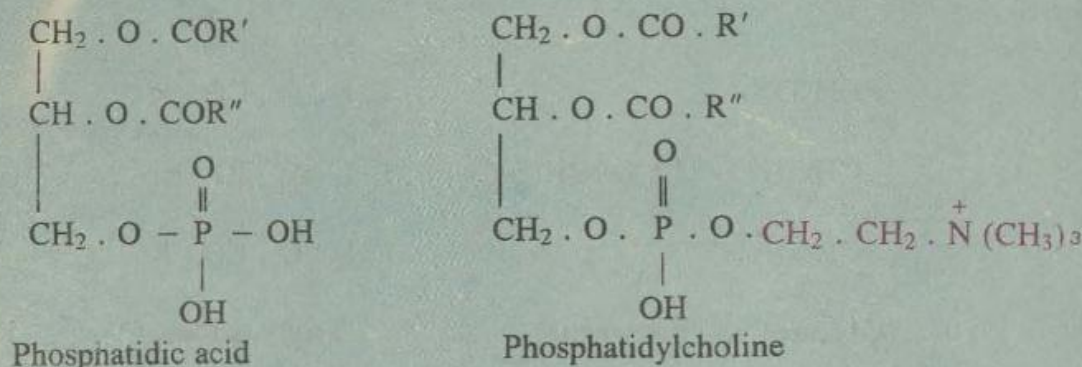


Fig. 3.10. Phosphatidic acid is composed of glycerol, 2 fatty acids on C1 and C2 and a phosphoric acid on C3 of glycerol. In phospholipid a nitrogenous base (e.g. Choline) is attached to phosphoric acid of phosphatidic acid.

d. Terpenoids

Terpenoids are a very large and important group of compounds which is in actual fact made up of a simple repeating units, isoprenoid unit (Fig. 3.11). This unit by condensation in different ways gives rise to compounds such as rubber, carotenoids, steroids, terpenes etc.

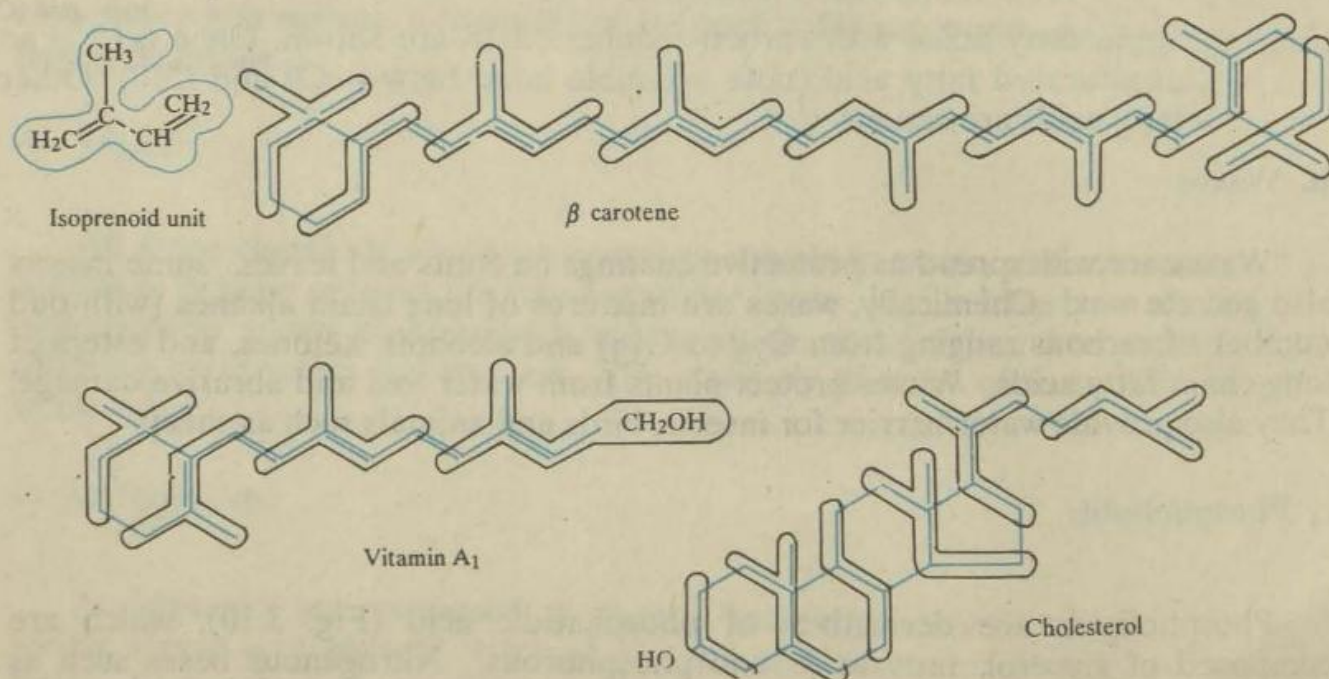


Fig. 3.11. Some terpenoids formed by condensation of isoprenoid units.

Lipids constitute major source of energy, and play an intimate role in the structure of membranes of the cell and of organelles found in the cell.

5. Nucleic acids

Nucleic acids are polynucleotide chains, in which units known as nucleotides are linked to each other by ester linkages. There are two types of nucleic acids viz. **Ribonucleic acid** (abbreviated as RNA) and **deoxyribonucleic acid** (abbreviated as DNA). DNA is generally located inside the nucleus, while RNA is concentrated in the cytoplasm. DNA is made up of deoxyribonucleotides, while RNA is composed of ribonucleotide. Typically a nucleotide is composed of three components i.e. pentose sugar, nitrogenous base, and phosphoric acid. Pentose sugar in ribonucleotide is ribose, while in deoxyribonucleotide, it is deoxyribose (Fig. 3.12). Nitrogenous bases (Fig. 3.12) are of two types i.e. purine and pyrimidine. Purine bases include adenine (A) and guanine (G), while pyrimidine bases include cytosine (C), thymine (T) and uracil (U). DNA contains A, T, C and G, while RNA does not contain T, but instead contains uracil.

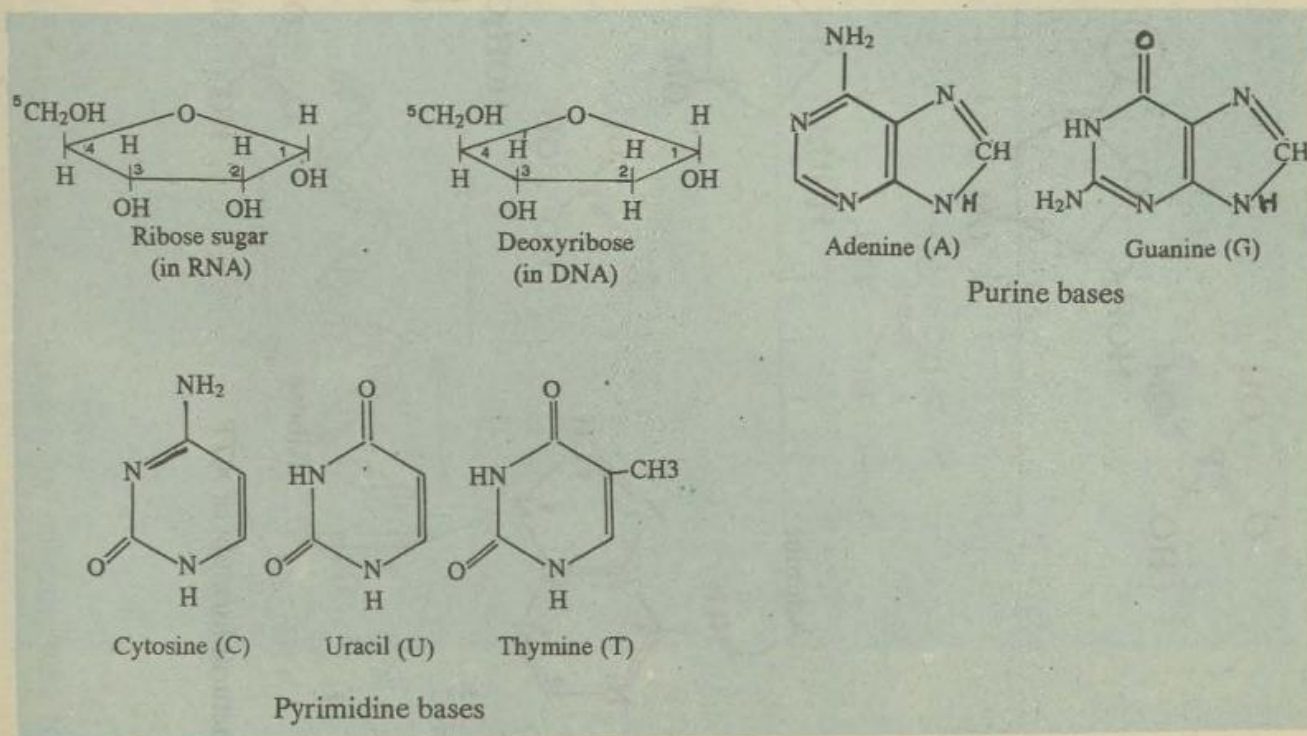


Fig. 3.12 Structural formulae of pentose sugar and nitrogenous bases of nucleic acids.

Phosphoric acid (H_3PO_4) has the ability to develop ester linkage with OH groups of pentose sugar. In a typical nucleotide (Fig. 3.13), the nitrogenous base is attached to position 1 of pentose sugar, while phosphoric acid is attached to position 3 of pentose sugar in front and position 5 of pentose sugar behind it. Since phosphate forms a double ester linkage with pentose sugar, the linkage is known as phosphodiester linkage (Fig. 3.13).

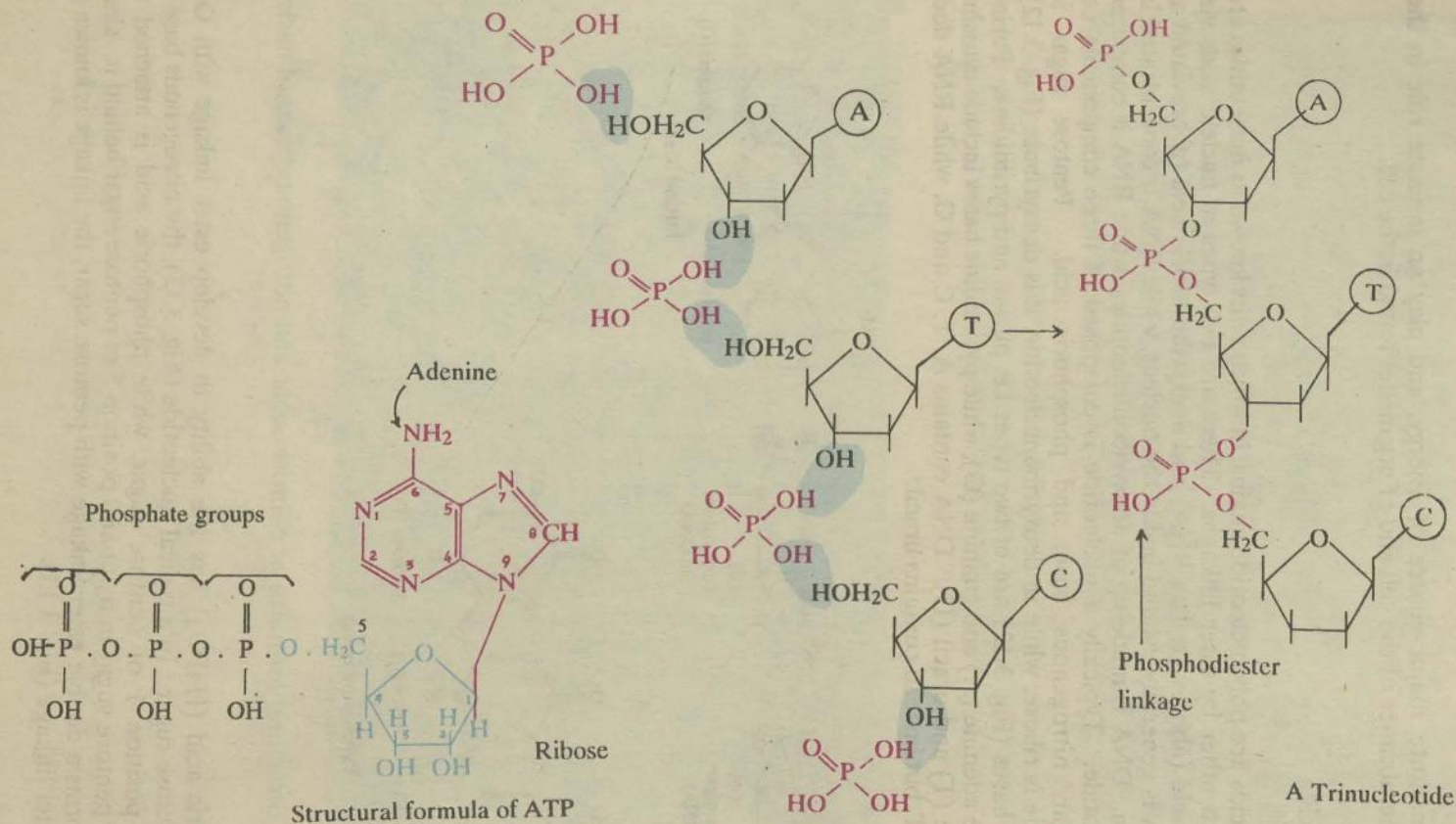


Fig. 3:13. Three nucleotides are linked to form trinucleotide. Note the structure of phosphodiester linkages. Structural formula of ATP, a nucleotide, is shown to highlight bonding between different components of a nucleotide.

Table II: Amount of DNA/nucleus in different types of cells of chicken and carp.

	Amount of DNA/nucleus (in picogram)	
	Chicken	Carp (Fish)
RBC	2.3	3.3
Liver cells	2.4	3.3
Kidney cells	2.4	3.3
Sperm cells	1.3	1.6

DNA is a heredity material and contains the genetic information which is passed on from one generation to another. The evidence that DNA is the genetic material came first from studies on a bacterium known as *Pneumococcus*. Avery, Mcleod and McCarty provided experimental evidence to prove that virulence of *Pneumococcus*, which is due to its smooth outer surface, can be transmitted to bacteria, which have secondarily lost their virulence by mutation. Conclusive

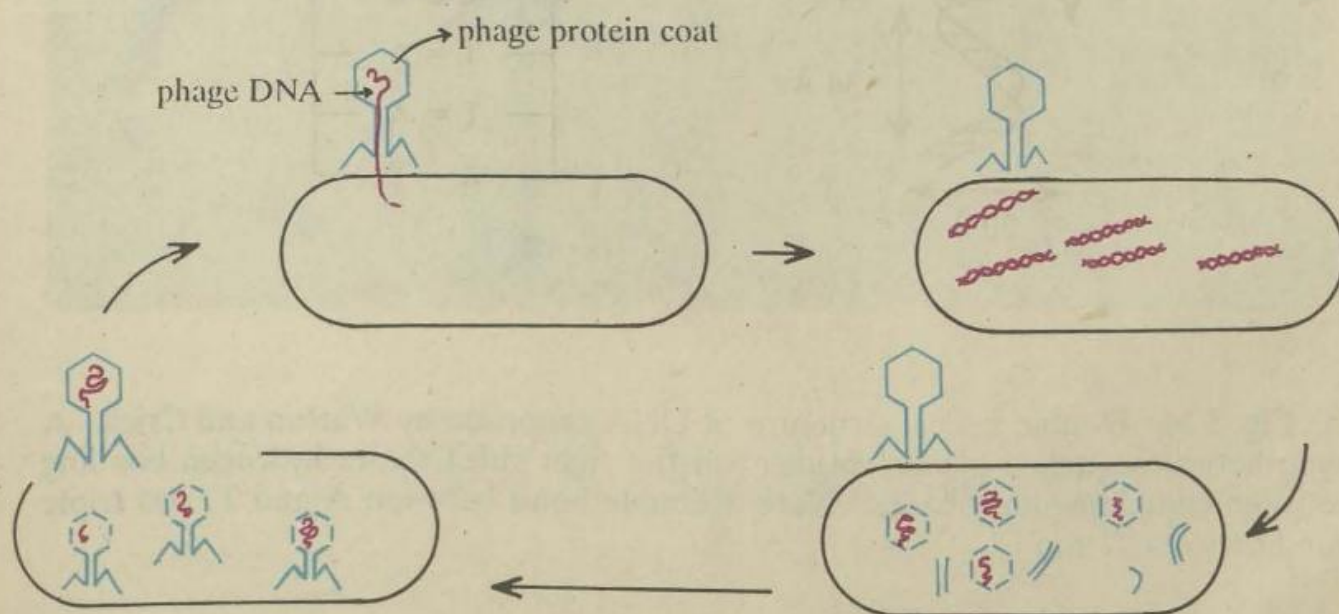


Fig. 3.15 Infection of *E. coli* with a phage virus. Coat protein is lifted out, while DNA is injected into the bacterium. New progeny of virus particles will appear under the instructions of viral DNA. The protein synthetic machinery of bacterium is used for this purpose.

evidence was provided by Hershey and Chase who studied life history of bacterial viruses. Bacterial viruses consist of DNA, which is enclosed in a protein coat. At the time of infection, the viruses inject their DNA into a bacterium, while protein coat is left out in the process (Fig. 3.15). The new viruses are made inside the host bacterium, under the instruction of viral DNA which was injected in the bacterium. Obviously DNA is the genetic material.

DNA functions in the cell with the help of RNA. There are three types of RNA molecules viz. **messenger RNA** (abbreviated as mRNA), **ribosomal RNA** (abbreviated as rRNA) and **transfer RNA** (abbreviated as tRNA). All these three types of RNAs are synthesized from DNA in the nucleus and then move out in the cytoplasm to perform their characteristic functions. Ribosomal RNAs along with protein constitute ribosomes, which are the sites of protein synthesis. Transfer RNAs pick up amino acids and transfer them to ribosomes, where they are linked to each other to form protein. Messenger RNA carries the genetic information from DNA to ribosomes, where amino acids are arranged according to the information in mRNA to form specific protein molecules.

7. Enzymes

The enzymes are complex organic compounds present in the cells of all organisms. They control and speed up the chemical reactions in the cell. They are specific in their chemical reactions. In complex metabolic reactions, each enzyme speeds up only a particular step. Being catalytic agents, they remain chemically unchanged after accelerating a reaction.

It is difficult to study enzyme action in living cells, i.e. in vivo, because their molecules are very small in size and they work at a great speed. A single enzyme molecule may break down 100,000 molecules of other substance in a single second, so they are studied outside the body, in controlled environment i.e. in vitro.

After the isolation of first enzyme, diastase by Payen and Persoz, hundreds of enzymes have been isolated in pure form. Many of them have been obtained in crystalline form as well. Enzymes are protein in nature. They are assisted by other substances called **co-enzymes**. The co-enzymes are not protein, and are smaller in size than protein.

Enzymes are very important for the cells. Many different kinds of enzymes work closely together, speed up the slow reactions and produce unexpected result. The substances, on which the enzymes act, are called **substrates**.

8. Inorganic salts

In most of cells protoplasm consists of more than 75% water and less than 25%

dry matter. The dry matter consists of about 90% organic and 10% inorganic compounds. Numerous inorganic salts are found in a cell but these are quite small in quantity. Protoplasm is not merely a mixture but it is a balanced, organized system of substances combined in definite proportions and specific patterns.

QUESTIONS

1. Describe the physical properties of protoplasm.
2. Write a short note on nucleic acids.
3. What are proteins? Describe their structure and function.
4. Write a brief note on Carbohydrates.
5. Distinguish between Proteins and Carbohydrates.
6. Define enzyme, coenzyme and substrate. What are their properties?
7. Sketch a nucleotide, a phospholipid, an amino acid and a glucopyranose.
8. Give approximate chemical composition of a typical bacterial cell and a mammalian cell.

REPRODUCTION OF CELLS

4

Reproduction involves the multiplication of cells. The formation of a bud in a simple animal like Hydra, the development of sex cells, and the growth of a young animal or plant into an adult all involve cell multiplication.

In order to multiply, cells undergo cell division: one divides into two, two into four, four into eight, and so on. The word division is misleading in some ways because it implies that the process always involves halving the cell and its contents. In fact we now know that cell division is accompanied or preceded by the formation of new cell components so that the products of cell division, the daughter cells, are essentially similar to the parent cell. Understanding cell division is largely a question of appreciating how this uniformity is preserved.

CHROMOSOMES - THEIR ORGANIZATION

Chromosomes are important components of the cell and were discovered by Waldeyer (1876). Soon after their discovery, many biologists became interested in their role and it was established by W. S. Sutton (1908) that units of inheritance (genes) are located on the chromosomes and genetic phenomenon can be explained in terms of chromosomal behaviour during cell division.

At the onset cell division, the chromatin material of the nucleus condenses into chromosomes. The morphology of the chromosome is best studied during metaphase and anaphase of cell division. A typical chromosome (Fig 4.1) during these stages, comprises of two chromatids (un-separated replica of the chromosome) attached to the same centromere, where spindle fibres get attached during cell division. The position of the centromere on the chromosome is very important as it determines the shape of the chromosome and is a basis for the identification of chromosomes from one another. Chromosomes are often classified into four types on the basis of centromeric position (Fig. 4.2). **Telocentric** chromosomes have the centromere located at one end of chromosome. **Acrocentric** chromosomes have a very small or short arm. **Submetacentric** chromosomes have arms of unequal length and **Metacentric** chromosomes have

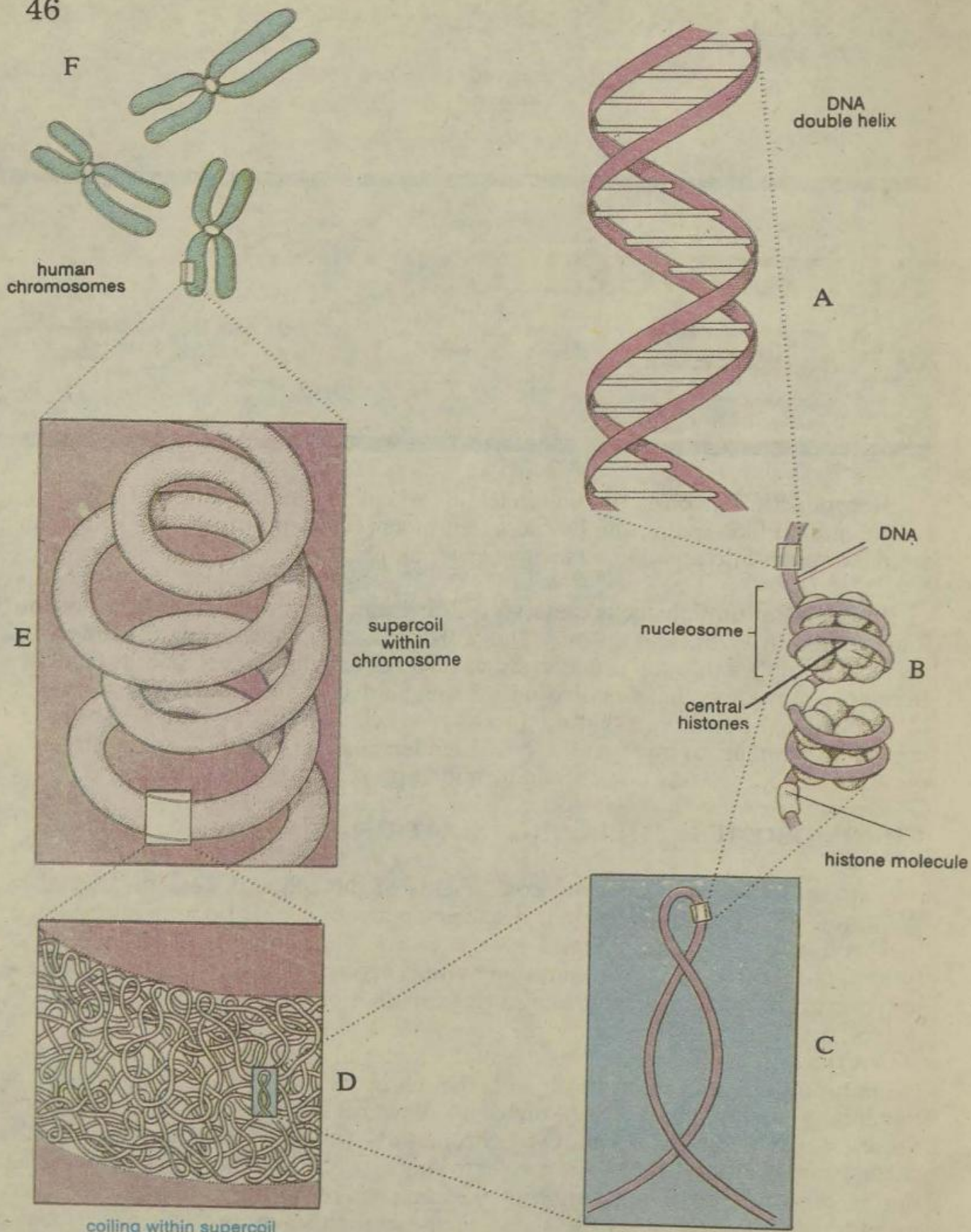


Fig 4.1 Levels of chromosomal organization. The DNA duplex, A, is wound twice around aggregates of histone proteins to form nucleosomes, B, and the string of nucleosomes is further coiled in a series of condensation stages, C to E. During cell division chromosomes are fully condensed, F. In interphase (not shown here) much of the coiling is relaxed and chromosomes are not visible as discrete entities under the light microscope.

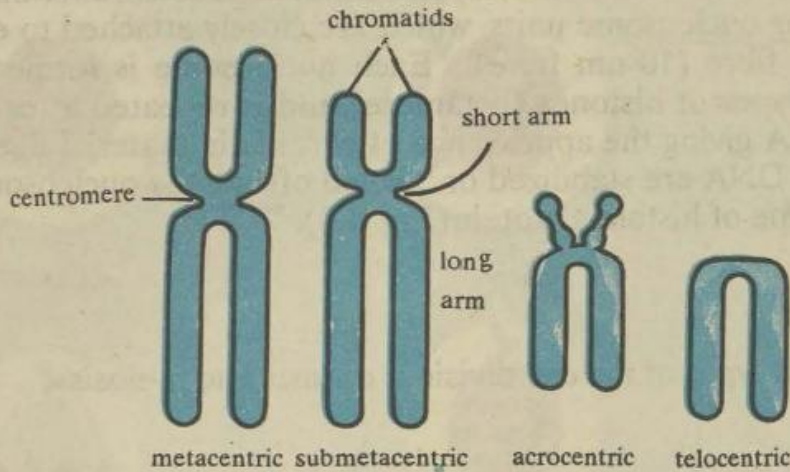


Fig. 4.2 Chromosomal type on the basis of centromeric position.

equal or almost equal arms. Apart from this classification, chromosomes vary from each other due to their size, thickness and other characters as well. **Karyotype** is a term given to the total chromosome complement of a cell. This involves the number of chromosomes, their relative size and position of centromere etc. So the study of karyotype helps us in the identification of chromosomes in the human and other species.

Chemical composition of chromosome has revealed that it is composed of DNA and basic proteins called **histones**. DNA and histones together form a structure

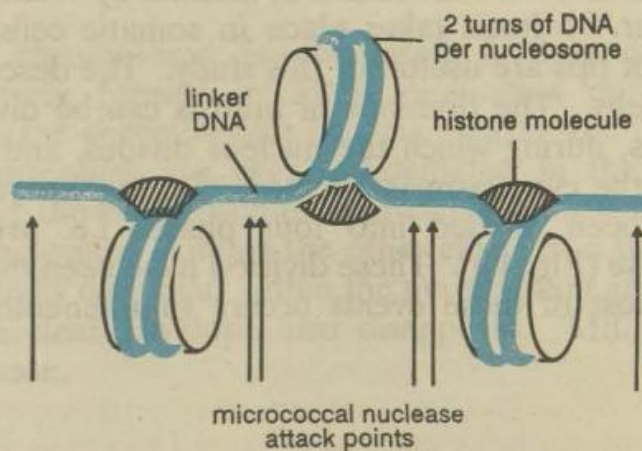


Fig. 4.3 Diagram illustrating the effect of nucleases on chromatin. Intact chromatin, note that the nucleosome is flat and that each histone octamere has two turns of DNA sealed off by histone

called **nucleosome**. Under the electron microscope, nucleosome can be visualised as beads about 10 nm (1 nm = 10^{-9} meter) in diameter. The chromatin is formed by a series of repeating nucleosome units, which are closely attached to each other to form a continuous fibre (10 nm fibre). Each nucleosome is formed by eight molecules of various types of histones (octamere) and is repeated after every 200 nucleotides of the DNA giving the appearance of chromatin material like beads on a string. Two turns of DNA are stabilized or "sealed off" on the nucleosome by one molecule of another type of histones protein (Fig. 4.3).

CELL DIVISION

There are two main types of the cell division, mitosis and meiosis.

1. MITOSIS

Mitosis is a type of cell division during which the diploid number ($2n$) of chromosomes is kept constant in the daughter cells. Mitosis involves a series of complex changes in both the nucleus and the cytoplasm. Before the cell divides by mitosis, its basic components have already duplicated, specially the DNA, during interphase.

Interphase

Interphase is a very active phase of cell cycle during which the DNA and histones are duplicated and various proteins which are necessary for cell division are synthesized.

Events of the Mitosis

The process of cell division was studied in animals by Walther Flemming and in plants by Strassburger. Mitosis takes place in somatic cells. Plant meristems, particularly young root tips are useful for this study. The description given here is based upon animal cells. The divisions of mitosis can be divided into two main phases - **karyokinesis**, during which the nucleus divides, and **cytokinesis** when a complete division of the cytoplasm is affected. During **karyokinesis** the various nuclear events had been divided into four phases i.e. **prophase**, **metaphase**, **anaphase** and **telophase** (Fig. 4.4). These division have been made for convenience of study otherwise most of these events occurs simultaneously which are given below.

Prophase

The initiation of prophase is indicated by the appearance of the chromosomes as thin threads in the nucleus. The chromosomes begin to make their appearance by the process of condensation which occurs by coiling and folding of the chromatin fibres present in the nucleus.

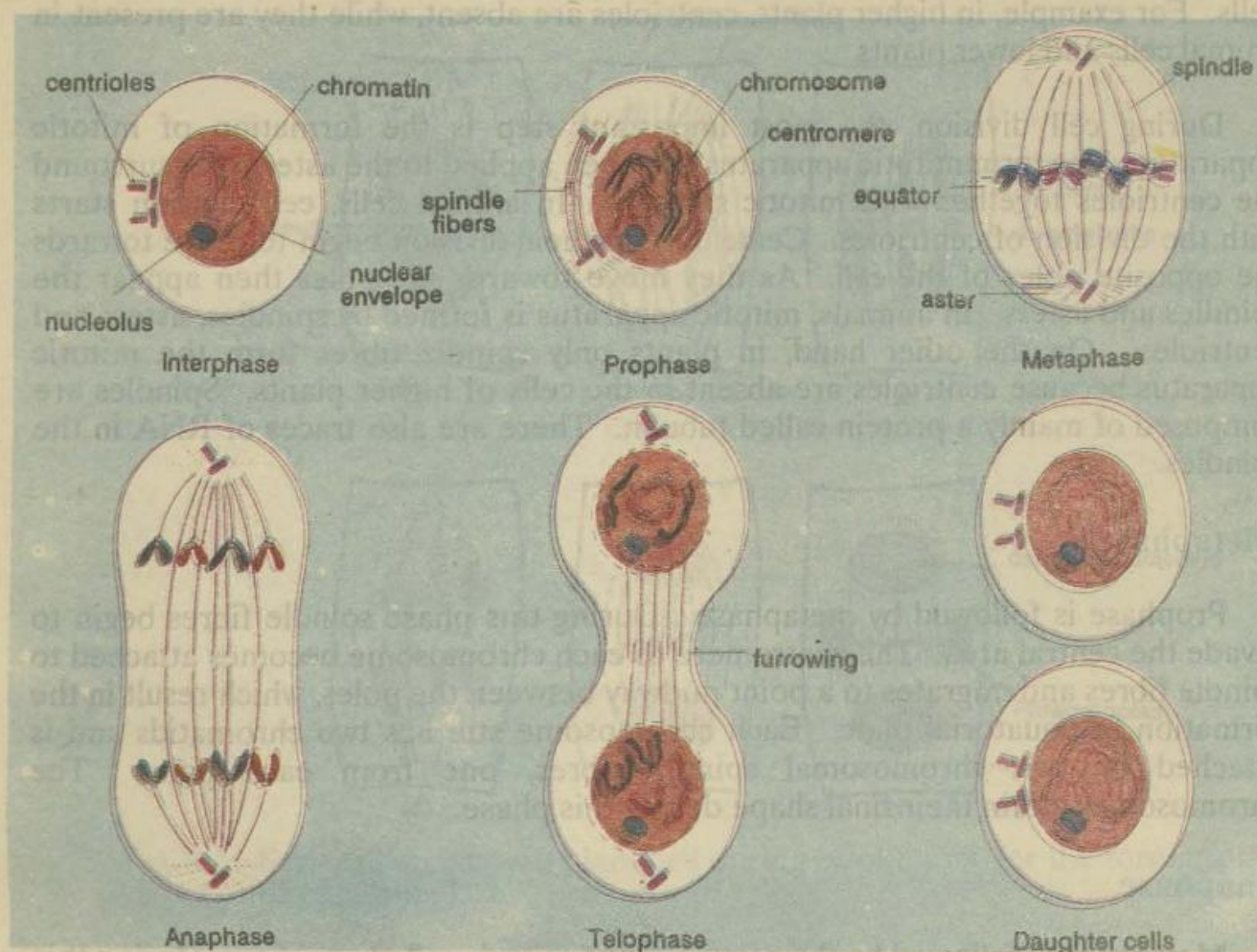


Fig. 4.4 Mitosis has four stages, excluding interphase and daughter cells. In these drawings, the daughter cells are shown in late interphase (following duplication of chromosomes) since it is assumed that each will be dividing again.

Each prophase chromosome is composed of two coiled filaments, the chromatids, which were formed by DNA replication during interphase. As prophase progresses, the chromosomes become shorter and thicker. During early prophase, the chromosomes are evenly distributed in the nucleus. With the progress of this stage, the chromosomes approach the nuclear envelope which still surrounds the chromosomes. Among the other changes in the nucleus during this phase, nucleoli gradually disappear within the nucleoplasm and finally at the end of the prophase, the nuclear envelope also disappears. Mitotic apparatus is also formed during prophase.

Mitotic Apparatus

In all eukaryotic cells there is similarity in overall process of mitosis. But, variations exist between different organisms especially between animal and plant

cells. For example, in higher plants, centrioles are absent, while they are present in animal cells and lower plants.

During cell division, the most important step is the formation of mitotic apparatus. The term mitotic apparatus has been applied to the asters that surround the centrioles together with mitotic spindles. In animal cells, cell division starts with the division of centrioles. Centrioles on their division begin to move towards the opposite poles of the cell. As they move towards the poles then appear the spindles and asters. In animals, mitotic apparatus is formed by spindles, asters and centrioles. On the other hand, in plants only spindle fibres form the mitotic apparatus because centrioles are absent in the cells of higher plants. Spindles are composed of mainly a protein called tubulin. There are also traces of RNA in the spindles.

Metaphase

Prophase is followed by metaphase. During this phase spindle fibres begin to invade the central area. The centromere of each chromosome becomes attached to spindle fibres and migrates to a point midway between the poles, which result in the formation of equatorial plate. Each chromosome still has two chromatids and is attached by two chromosomal spindle fibres, one from each pole. The chromosomes attain their final shape during this phase.

Anaphase

Metaphase is followed by the next phase of mitosis called anaphase. During this phase, a pull is exerted by spindles on the centromere of the chromosome. Due to this pull the centromere divides, with the result that the chromatids separate and begins to move towards their respective poles. The condensation of the chromosomes also reaches to its peak during early anaphase. Chromosomes move in two sets, one set towards each pole. The result is that chromosome number remains diploid in each set

Telophase

Telophase is the reverse of prophase. Once the chromosomes reach their poles, they begin to uncoil. The nucleoli reappear. A nuclear membrane begins to form around the chromosomes. At the end of telophase, the result is the formation of two daughter nuclei.

The next step is the division of the cytoplasm. This division of the cytoplasm is called **cytokinesis**. Cytokinesis in animal cells starts by the constriction of the cell membrane and cytoplasm, in the equatorial area and as this constriction deepens, the cell divides into two daughter cells

In plant cells at anaphase, the equatorial of the spindle fibres, get transformed

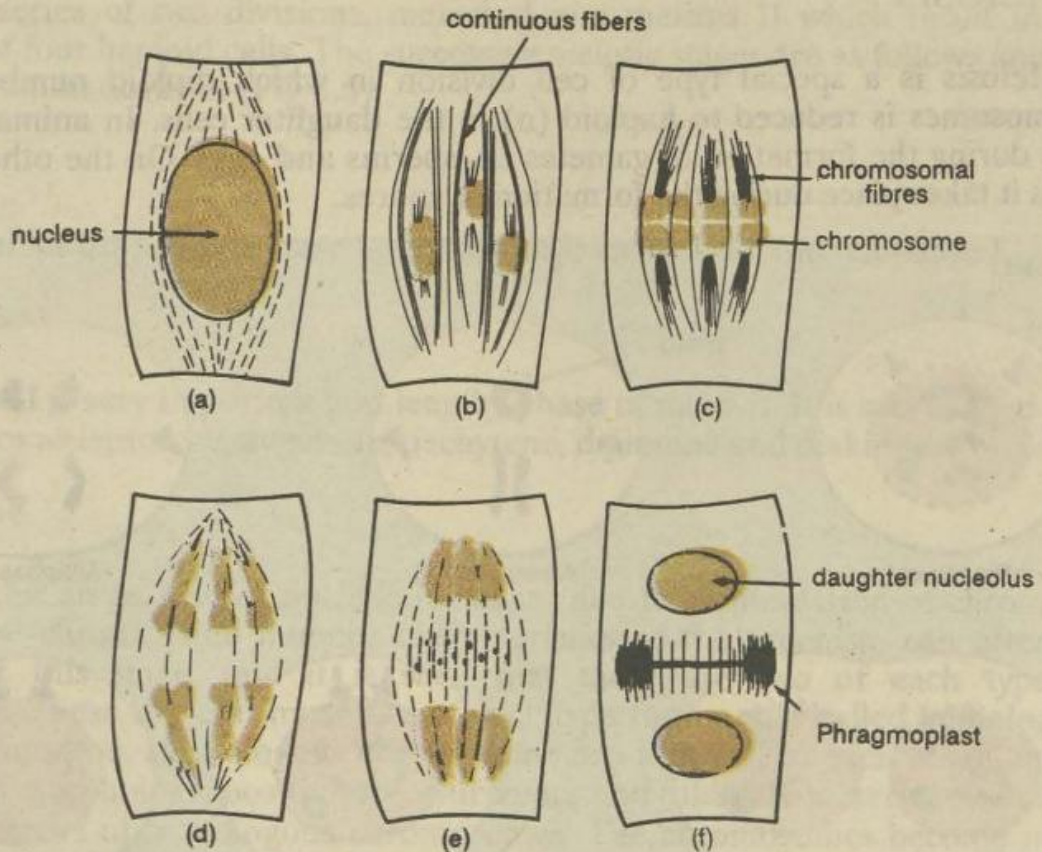


Fig. 4.5 Series of changes in plant cell during cytokinesis, for the formation of phragmoplast.

into a structure called **phragmoplast**. Initially phragmoplast is found in the middle region of the cell but then it extends across the entire equatorial plane until the two daughter cells become separated (Fig.4.5).

Significance of Mitosis

Chromosomes contain the information that control the development and activities of the cell. Mitosis is a means of orderly duplication and separation of chromosomes and thus the continuity of the hereditary information is ensured. Each daughter cell gets a complete set of chromosomes identical to that of the parent cell. Mitosis thus provides mean of transmitting information unchanged to the daughter cells. With few exceptions, all kinds of asexual reproduction are carried out by mitosis. Vegetative propagation in plants is also based upon mitotic activity of the vegetative parts. After the formation of zygote, mitosis is of utmost importance. As a result of mitotic activity, a great number of cells are formed which then differentiate into tissues. These tissues then form organs and ultimately organs collectively make a new individual.

Mitosis also plays an important role in the life of an organism, e.g. healing of wounds is dependent upon the mitotic division of underlying cells. The production of new somatic cells, such as blood cells also depends on mitosis.

2. MEIOSIS

Meiosis is a special type of cell division in which diploid number ($2n$) of chromosomes is reduced to haploid (n) in the daughter cells. In animals, it takes place during the formation of gametes i.e. sperms and eggs. On the other hand, in plants it takes place during the formation of spores.

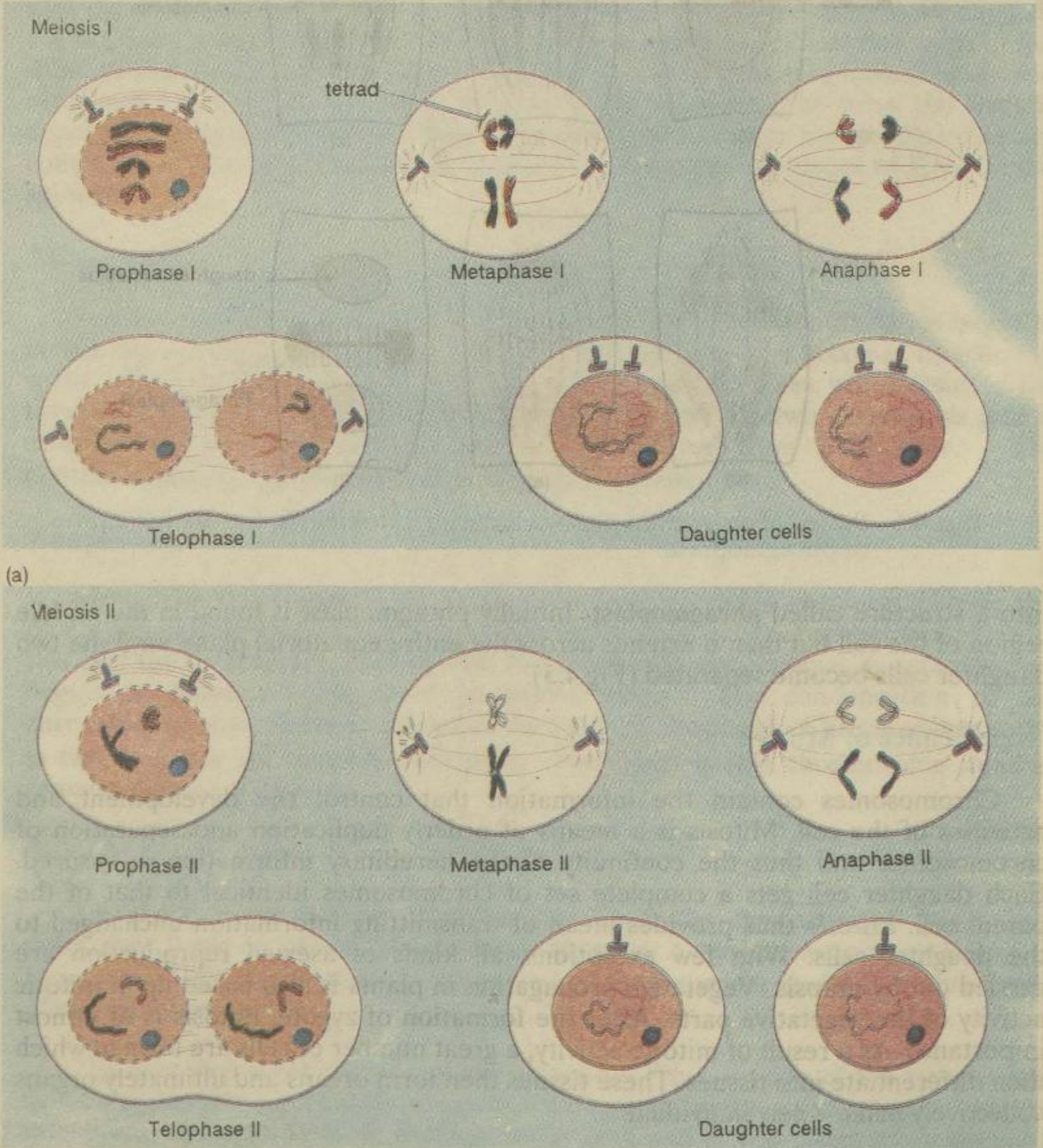


Fig. 4.6 a. Meiosis I requires a complete set of stages.

b. For the sake of simplicity, meiosis II, which also requires a complete set of stages, is shown only for one daughter cell from (a).

It is a series of two divisions, meiosis I and meiosis II which result in the formation of four haploid cells. The successive meiotic stages are as follows and are shown diagrammatically in (Fig 4.6).

Meiosis I

Meiosis-I consists of prophase I, metaphase I, anaphase I and telophase I.

a. Prophase I

Prophase I is very important and lengthy phase of meiosis. It is sub-divided into various stages as leptotene, zygotene, pachytene, diplotene and diakinesis.

(i) Leptotene

During this stage, size of nucleus increases due to condensation of chromatin material. The chromosome number characteristics of the organism can often be discerned at this stage, and it is seen that there are two of each type of chromosome. These two chromosomes of each type form a pair called **homologous** pair of chromosome. Homologous chromosome are identical to each other on the basis of their morphology, position of centromere and other characteristics. In man there are 23 pairs of homologous chromosomes. The chromosomes become more apparent, and distinct.

(ii) Zygotene

During this phase each chromosome in the cell begins to pair up length wise with its homologue. The process by which homologous chromosomes begin to pair with each other is called **synapsis**. The process of pairing does not have a special starting point on chromosomes. There is no pairing between homologous chromosomes during mitosis.

(iii) Pachytene.

The pairing of the chromosomes reaches to completion. The chromosomes become shorter and thicker due to condensation of the chromatin material. Each unit is called a **bivalent** or **tetrad** because it is formed by two homologous chromosomes, and four chromatids. The homologous chromosomes exchange their segments during this period by the formation of **chiasmata**. This exchange of chromosomal segments is called crossing over.

(iv) Diplotene

When pairing is completed and chiasmata are established then the paired chromosomes repel each other with the result that they begin to separate but they are held together at the chiasmata. There is at least one chiasmata in each bivalent.

Diplotene can last for months or years. The chromatids of the tetrad are clearly visible during this stage due to the progress in condensation cycle.

5. Diakinesis:

The tetrads established during earlier phase are more evenly distributed in the nucleus. The nucleoli disappear. The number of chiasmata begins to reduce. As the diakinesis reaches to its end, the homologous chromosomes are held together only at their ends. The nuclear membrane is still present around the chromosomal materials.

b. Metaphase I:

Nuclear envelope breaks down. The spindle fibres begin to attach to the centromeres. The chromosomes become arranged at the equator. Chromosomes become arranged in pairs on the equatorial plate. Only spindle fibre from the pole attaches to each chromosome.

c. Anaphase I:

At this stage one chromosome from each bivalent begins to move towards its respective pole by the contraction of spindle fibres. Anaphase I is different from mitotic anaphase, because half the number of chromosomes move to each pole.

d. Telophase I:

When chromosomes reach toward the poles, each pole receives haploid number of chromosomes. Nuclear envelope and nucleolus are reformed.

Meiosis II

After the completion of first meiotic division, second meiotic division starts. This division comprises of Prophase II, Metaphase II, Anaphase II and Telophase II. This is similar to mitosis, but it maintains the haploid number of chromosomes in the daughter cells.

Significance of Meiosis

Meiosis is a type of division, in which the numbers of chromosome is reduced to half in reproductive cells (gametes). The full number of chromosomes is restored after fertilization. Therefore, meiosis helps in maintaining chromosome numbers constant from generation to generation.

Another significant feature of meiosis is that it produces gametes with varied combination of genes. Crossing over takes place when homologous pairs are in

synapsis, Chiasmata are formed and homologous chromosomes exchange parts (genes) and thus gametes with genetic variability are produced. Both crossing over and random assortment ensures that progeny resulting from sexual reproduction will be genetically different from their parents. These differences are basis of evolution and provide raw material for this process.

QUESTIONS.

1. Explain the structure and chemical composition of the chromosomes?
- 2.a What are various types of chromosomes on the basis of the position of centromere?
- b How mitosis in animals is different from that of plants?
3. How mitosis maintains the chromosome number constant in daughter cells? Explain various stages involved during this process.
- 4.a What is meiosis? How is it different from that of mitosis?
- b Explain the significance of meiosis with the help of checker board.
5. Meiosis is a very significant division to maintain the chromosome number constant, in a species generation after generation, how?

DIVERSITY OF LIFE

VIRUSES AND PROKARYOTES

5

There are over two million kinds of living organisms present on earth today. They show a lot of diversity in their size, shape, colour, structure and reproduction. In this section major groups of living organisms will be discussed.

VIRUSES AND PROKARYOTES

Viruses are unique due to the fact that they do not fit with any other group in the classification of living organisms. Scientists still are not able to decide whether viruses are living or non living. Bacteria and Cyanobacteria (blue green algae) are prokaryotes. Some scientists have included them in the kingdom Monera. Prokaryotes differ from eukaryotes (fungi, algae, land plants and animals) in several basic features, you have already studied.

VIRUSES

Viruses are important in the study of biology. They are tiny particles composed largely of nucleic acid and proteins and can reproduce only inside living host cells. Viruses were discovered in the late 19th century. It was found that infectious agents that cause tobacco mosaic disease would pass through filters that stopped all known bacteria.

In 1892 a Russian biologist named Iwanowsky demonstrated that a virus could be transmitted from an infected organism to a healthy organism of the same kind. In 1935 W.M.Stanley isolated tobacco mosaic virus from the host cell.

Viruses have been divided into three groups:

1. Animal viruses causing disease in man and other animals.
2. Plant viruses, causing disease in plants.
3. Bacterio-phages or phage viruses that attack bacterial cells.

Various important viral diseases of man are influenza, measles, mumps, chicken pox, common cold, poliomyelitis and small pox. Among economically important plants affected by viruses are potato, tomato, sugar cane, corn, sugar beet, wheat

and rice. In recent years, we have acquired an enormous amount of information about viruses.

Shape and Size

Viruses are too small to be seen even with the compound microscope. But we can study them under electron microscope. They are of different sizes and shapes. They range in size from 15 nm to 450 nm. Viruses may be rod shaped, may look like tadpoles or somewhat spherical and like golf balls. Most forms are poly-hedral with twenty sides.

Structure of a Virus

A phage virus consists of two parts, a head and a tail (Fig. 5.1). The head is many sided. Most viruses consist of only a coat of protein surrounding a core of

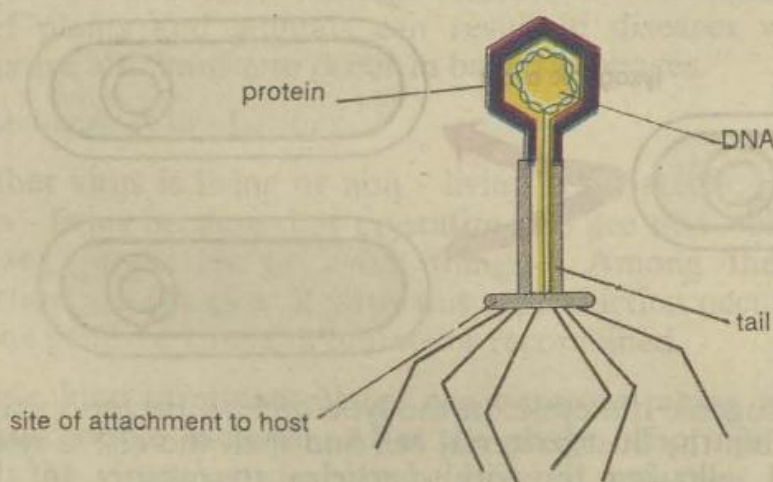


Fig. 5.1 A bacteriophage is composed of a DNA core and a protein coat.

nucleic acid. The nucleic acid of nearly all bacteriophages is DNA. Most animal viruses also contain DNA. But some animal viruses and most viruses of higher plants contain only RNA. Whether it is DNA or RNA the nucleic acid is the substance responsible for the specific characteristics of the virus.

Life - Cycle of a Bacteriophage

Bacteriophages are found in nature wherever bacteria occur. They are specially abundant in the intestine of man and other animals. There are many strains of bacteriophages and usually one kind of phage will attack only one species or one strain of bacterium. Two types of life-cycles, termed the lytic and lysogenic cycle have been observed in bacterio-phages (Fig. 5.2).

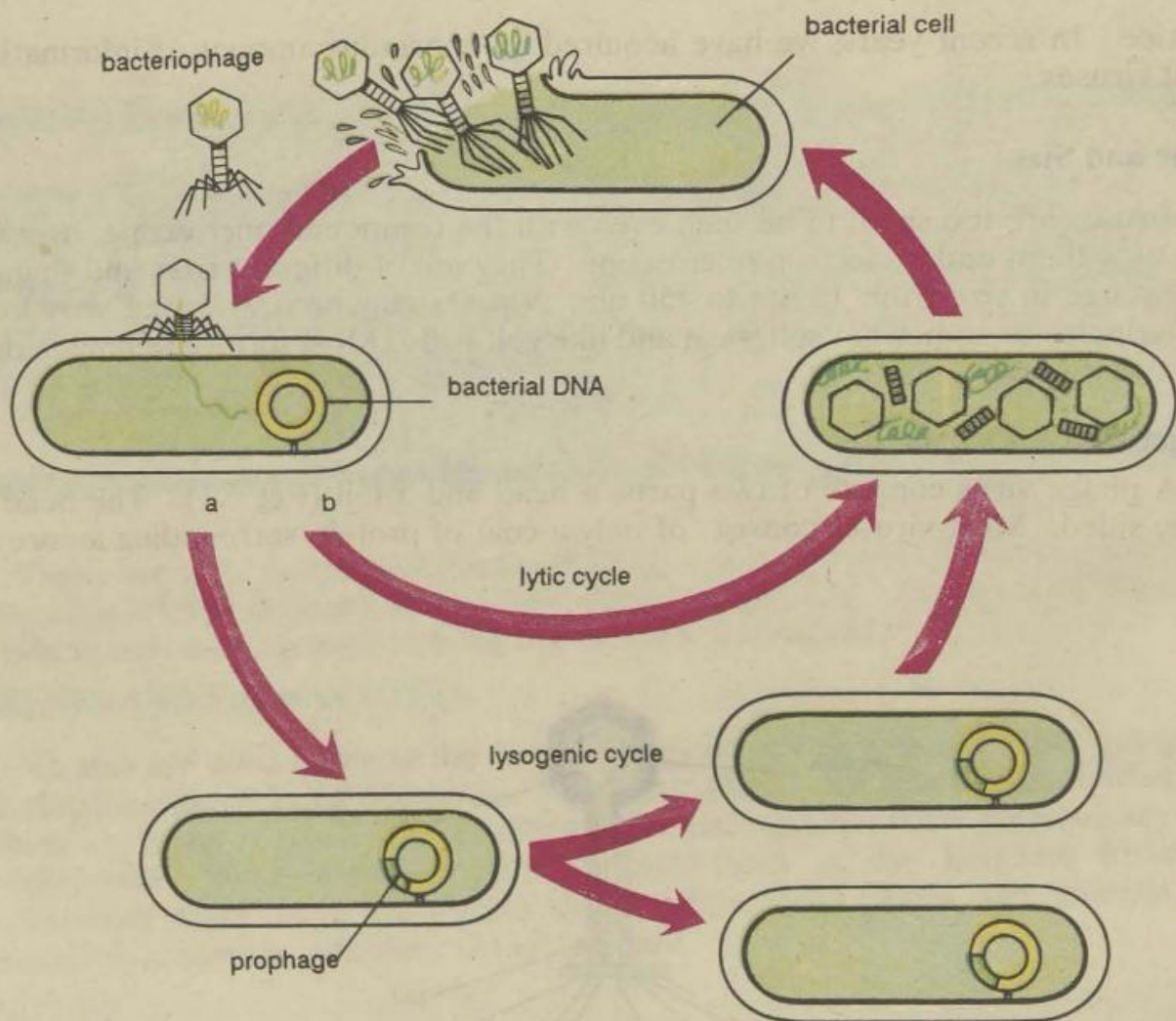


Fig. 5.2 Lytic versus lysogenic life cycle. In the lytic cycle, a bacteriophage reproduces within the host bacterial cell and then the cell is lysed (broken open), allowing the viral particles to escape. In the lysogenic cycle, the DNA of a bacteriophage integrates into the host DNA and becomes a prophage. Thereafter, the prophage is replicated along with the bacterial chromosome and passed to all the daughter cells. When and if the viral DNA leaves the chromosomes, the lysogenic cycle can be followed by the lytic cycle.

Lytic - Cycle

The virus first attaches to the bacterial cell by means of a protein tail. The tail contains an enzyme which digests part of the bacterial cell wall. The DNA of the virus is passed into the bacterial cell, while protein coat of the head and tail remains outside. DNA of the virus takes control of host cell's activities and a sort of master-slave relationship results. Inside the bacterial cell two important things happen. There is production of more phage DNA molecules and of new phage proteins that will provide the head and tail of the new phage. Materials of the host cell are used for this purpose. The DNA of the phage particles is incorporated into

the head portion. The bacterial cell then bursts or lyses releasing the mature phage particles. This type of cycle of a phage is called **Lytic Cycle** (Fig. 5.2).

Lysogenic - Cycle

The introduction of phage DNA into the bacterium does not always have such violent results. Apparently sometimes the DNA of phage and bacterium can combine or associate in peaceful coexistence. Virus DNA becomes a prophage. In this way, many new generations of bacteria are produced without any harmful results. Instead of a master-slave relationship, it is more like a host-guest relationship. The replication of the phage is geared exactly in time with the growth cycle of the bacterium. This cycle of the phage is called the **Lysogenic Cycle** (Fig. 5.2). Sometimes the phage becomes reactivated and destroys the bacterium by reproducing rapidly in its helpless hosts, as in the lytic phase.

Variability of Virus Types

Viruses are known to undergo mutations. Mutations in disease producing viruses of plants and animals can result in diseases with different symptoms. Mutations are also known to occur in bacterio-phages.

Viruses Living or Non - Living?

Whether virus is living or non - living is debatable. Some biologists consider them non - living because they crystalize and are non - cellular. However, viruses show many properties of living things. Among these, is the property of reproduction. In the case of virus this reproduction occurs only in the cells of the host. The genes of virus can mutate or recombined.

Certain kind of mutant phage can be grown along with normal phage in the cells of susceptible bacteria. After the phage offsprings have burst out from the host cell, the virus particles can be isolated and their hereditary characteristics tested. It has been discovered that not only the two parental types of phage (mutant and normal) are present among the offsprings, but also new forms in which characteristics of the parent viruses are combined. This reshuffling of heritable material is called genetic recombination which is an important characteristic of living things.

PROKARYOTES - Bacteria and Cyanobacteria

Bacteria and Cyanobacteria (blue green algae) are sometimes classified in a separate kingdom, the kingdom Monera. The main feature of cells of bacteria and Cyanobacteria, which distinguishes them from other organisms, is the absence of a distinct membrane - bounded nucleus. Such cells are called prokaryotic cells.

BACTERIA

Bacteria are probably the simplest and the smallest living organisms possessing cellular organisation. They may be found in any environment in which life can exist. They are found in soil, in both fresh and salt water, in air and even in

glaciers. They are abundant in the bodies of animals and plants, both living and dead.

Size and Form

Bacteria are divided into three types. This division is based on their shape.

1. *Cocci* (singular coccus) are spherical in form.
2. *Bacilli* (singular bacillus) are rod shaped.
3. *Spirilla* (singular spirillum) are spiral or cork - screw shaped (Fig. 5.3).

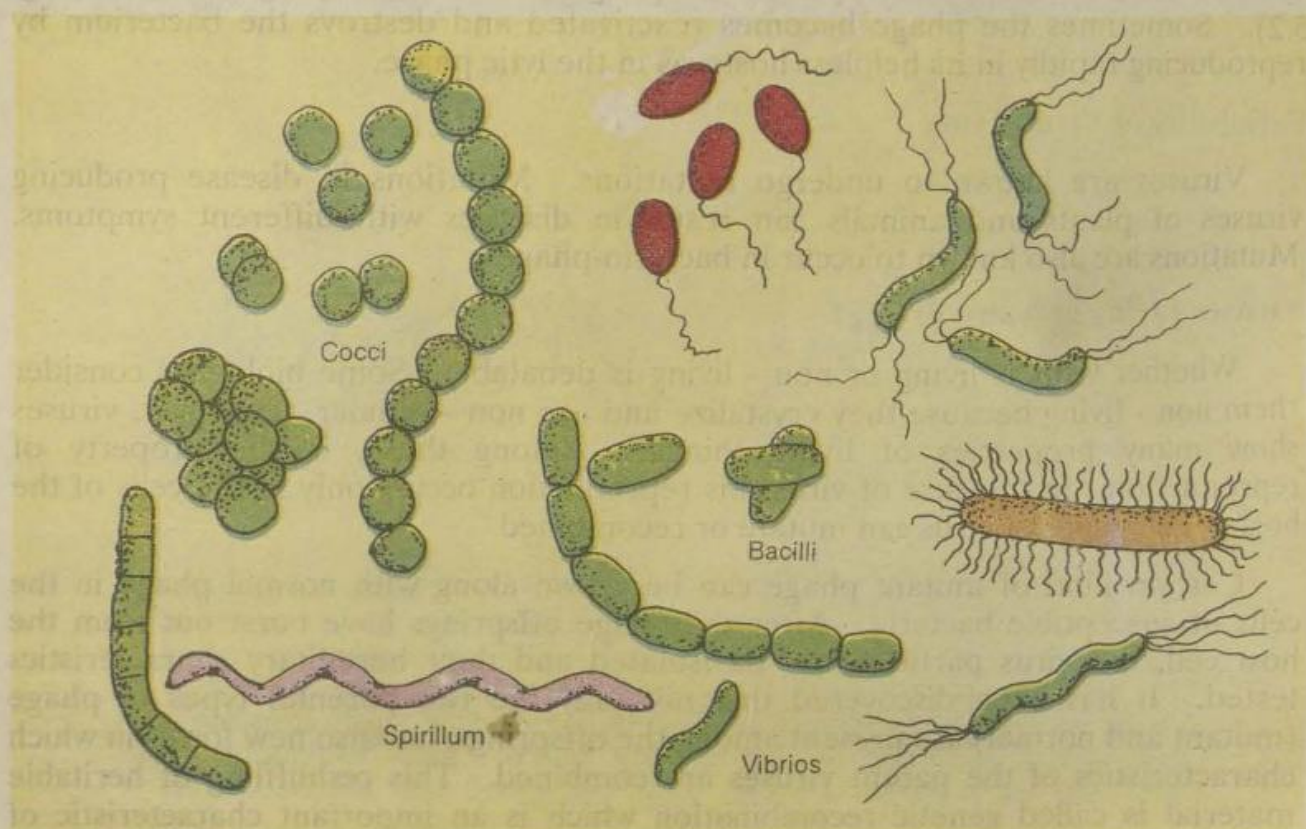


Fig. 5.3 Different shapes of bacteria and location of flagella.

Bacterial cells are small but are generally larger than viruses and can be seen with light microscope. They range in size from 1 to 10 μm (1 micrometer is 1/1000th of 1 mm) in length and from 0.2 μm to 2 μm in width.

Structure of a Bacterial Cell

Bacteria are one - celled organisms. In some bacteria the cells may occur in chains or clusters. The cell consists of a cell wall, cytoplasm and genetic material. The cell wall is chemically complex containing amino acids, sugars and other substances. Amino acids and sugars are linked to form peptidoglycan (murein).

Cellulose is absent from the bacterial cell wall. Most bacteria have a slimy capsule composed of polysaccharide. It lies outside the cell wall and serves as an additional protective layer. The cytoplasm within the bacterial cell is dense and contains granules of glycogen, protein and fat but lacks mitochondria and endoplasmic reticulum. The ribosomes occur free in the cytoplasm. The DNA is present in a distinct nuclear region called nucleoid but there is no nuclear membrane and no nucleolus. Bacteria are haploid organisms with a single chromosome. The bacterial chromosome consists of a circular double helical DNA molecule. One or more small, extrachromosomal circular rings of DNA may be present. These rings replicate when the cell replicates. Plasmids can also replicate independently of main chromosome. Such pieces of DNA are called **plasmids**. The cell membrane of a bacterial cell often invaginates to produce membranous structures called **mesosomes**. The mesosome is considered to be involved in cell division.

Many bacteria have whip like cellular outgrowths called **flagella**. The flagella differ in number and distribution in different species. Some bacteria have a single terminal flagellum, while others have one or a cluster of flagella at one or both ends of the cell. Still others are completely surrounded by flagella. Most motile bacteria are either bacilli or spirilla; cocci are usually nonmotile (Fig. 5.4).

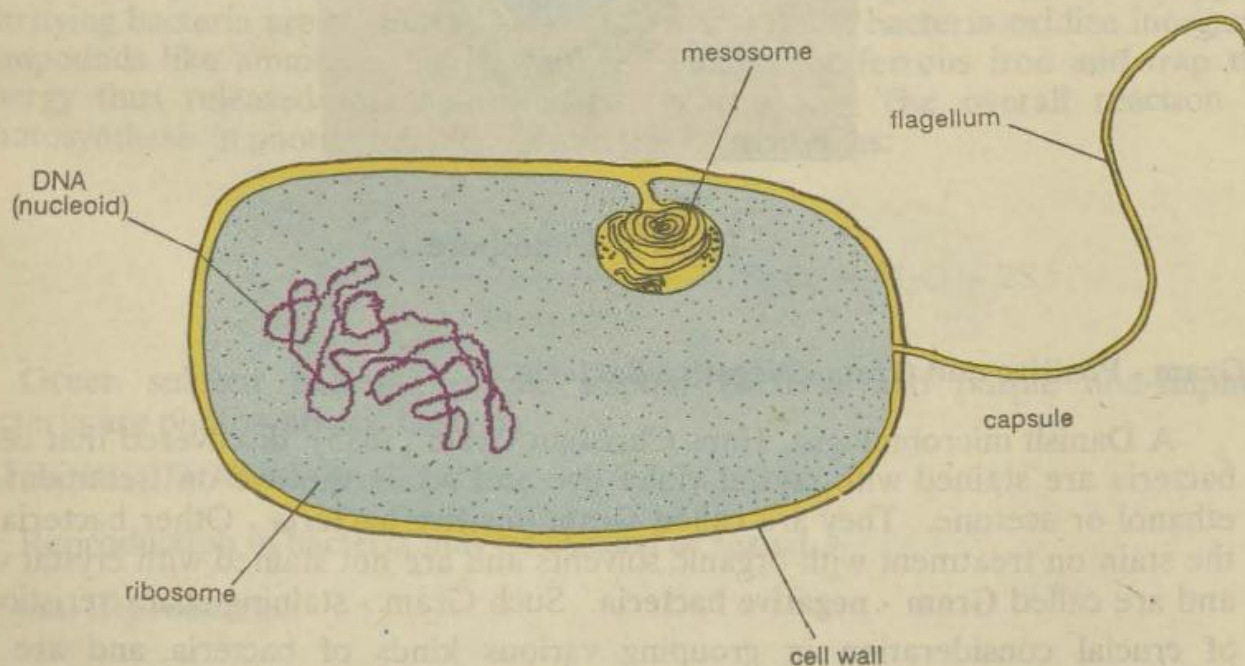


Fig. 5.4 Major structural features of a rod-shaped bacterium.

A unique feature of some bacteria is their ability to form endospores. They are small, round or oval, spore like structures formed within the parent cell wall. The endospore has a complex spore coat and is extremely resistant to heat, chemicals and dessiccation. They are usually formed under unfavourable conditions, especially the starvation, and are dormant structures. Under favourable conditions

the endospore germinates and gives rise to a single vegetative cell (Fig. 5.5). Endospores are mechanism for survival in adverse environmental conditions and not for increasing the number of individuals.

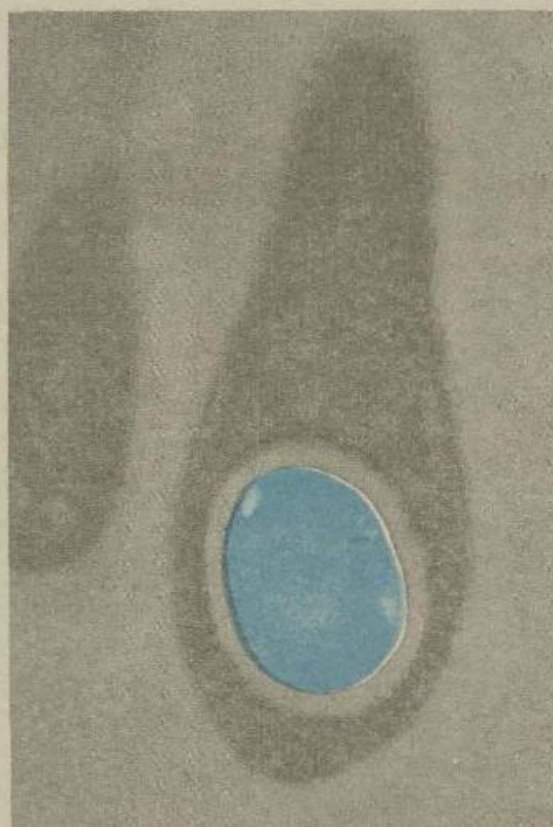


Fig. 5.5 Endospore

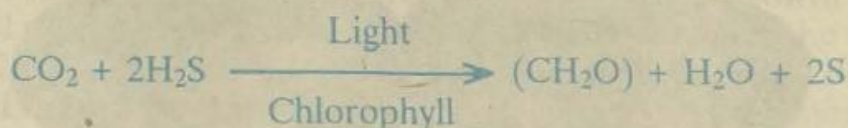
Gram - Positive and Gram - Negative Bacteria

A Danish microbiologist, Hans Christian Gram (1885) discovered that certain bacteria are stained with crystal violet dye and retain the dye on treatment with ethanol or acetone. They are called **Gram positive bacteria**. Other bacteria lose the stain on treatment with organic solvents and are not stained with crystal violet and are called **Gram - negative bacteria**. Such Gram - staining characteristics are of crucial consideration in grouping various kinds of bacteria and are also important in identification of bacteria in an unknown sample. Different staining characteristics of bacteria reflect chemical differences in the cell walls of Gram-positive and Gram-negative bacteria. The cell walls of Gram - positive bacteria are structurally simple and are mostly peptidoglycan in composition. The cell walls of Gram - negative bacteria possess additional cell wall components including lipopolysaccharides and lipid protein complexes. So Gram - negative bacteria have more lipid content and less peptidoglycan than Gram - positive bacteria.

NUTRITION OF BACTERIA

Like other organisms bacteria need energy for their growth, maintenance and reproduction. Most bacteria are **heterotrophic** i.e., they cannot synthesize their organic compounds from simple inorganic substances. They live either as the **saprophytes** or as **parasites**. Saprophytic bacteria get their food from dead organic matter. Soil is full of organic compounds in the form of humus. Humus is the material resulting from the partial decay of plants and animals. Many soil inhabiting bacteria have very extensive enzyme system that breaks down the complex substances of humus to simpler compounds. The bacteria can then absorb and utilize these simpler substances as a source of energy. Parasitic bacteria for their nutrition are fully dependent on their host.

Some kinds of bacteria are **autotrophic** i.e., they can synthesize organic compounds which are necessary for their survival from inorganic substances. These bacteria may be separated into two groups: photosynthetic autotrophs and chemosynthetic autotrophs. Photosynthetic bacteria possess chlorophyll which differ from the chlorophyll of green plants. Unlike most green plants, which have their chlorophyll in chloroplasts, bacterial chlorophyll is dispersed in the cytoplasm. During photosynthesis the autotrophic bacteria utilize hydrogen sulphide (H_2S) instead of water as a hydrogen source and liberate sulphur instead of oxygen. Nitrifying bacteria are chemosynthetic. Chemosynthetic bacteria oxidize inorganic compounds like ammonia, nitrate, nitrite, sulphur or ferrous iron and trap the energy thus released for their synthetic reactions. The overall reaction of photosynthesis in photosynthetic bacteria can be written as:



Green sulphur bacteria, purple sulphur bacteria and purple non-sulphur bacteria are photosynthetic bacteria.

REPRODUCTION OF BACTERIA

Reproduction in bacteria may be asexual or sexual.

Asexual Reproduction

Bacteria generally reproduce asexually by binary fission. This involves the division of the parental cell into two daughter cells (Fig. 5.6).

There is no spindle formation and no mitosis in bacteria. During fission the DNA is replicated and the two daughter chromosomes move apart into separate nuclear areas long before division of cytoplasm occurs. The plasma membrane grows inwards and partitions the parent cell into two daughter cells. The two daughter cells have characteristics essentially like those of the parent cell. Under ideal conditions of food, temperature and space, bacteria can divide about every 20

double-stranded DNA molecule

"old" strand

"new" strand

septum

(a)

(b)

Fig 5.6 Bacterial cell division

(a) This series shows binary fission in a bacterial cell. As DNA replication begins, the cell wall ruptures, and new plasma membrane is added between the two sites where the DNA molecules are attached to the membrane. The plasma membrane then folds inward, and new cell wall material is added in the septum to complete the division of the cell. (b) A dividing bacterial cell after the septum has formed.

minutes. At this rate in 24 hours one bacterial cell could theoretically produce a mass weighing about 2 million kilograms. However such growth never occurs. Instead, the reproductive rate is always slow because the food supply is used up and waste products accumulate.

Sexual Reproduction

Bacteria, strictly speaking, do not reproduce sexually. But evidence has been obtained of several mechanisms that bring about genetic re-combination. There are three ways by which sexual reproduction can take place in bacteria.

1. **Conjugation**
2. **Transduction**
3. **Transformation**

Conjugation

Conjugation is the process of genetic recombination between two organisms through a cytoplasmic bridge between them. Joshua Lederberg and Edward Tatum in 1946 worked on related strains of bacteria and demonstrated that conjugation takes place in bacteria. For this experiment they obtained two different bacterial strains which they wanted to cross. First they selected a "wild" type of bacteria that can synthesize all its protoplasm from a simple broth of glucose and inorganic salts. This wild type bacteria had the ability to synthesize substances which we can call A, B, C, D, E and F from simple diet not containing these substances. Lederberg and Tatum obtained mutant strains by irradiating the wild type bacteria. These strains were unable to synthesize certain compounds. One mutant strain could not synthesize compounds A, B and C but could synthesize D, E and F. Second strain could synthesize A, B and C but not the other three compounds D, E and F. It appears that six genes had been made to mutate, three in each mutant strain.

The two mutant strains could be grown together if the growth medium was supplied with all six compounds, three that one strain needed and the three that the other needed. If sexual reproduction could occur at all, it would be detected in the mixed culture of the two mutant strains. Thus if any cells were formed that had the mutant genes combined in new ways, we can suspect sexual reproduction.

The genetically different strains were brought together for several hours and given the opportunity to grow and reproduce in medium with all six substances. The next step was to isolate single cell from the mixed culture and test them for their nutritional requirements. Here we expect to find strains of offsprings exactly like the mutant parent strains that is some offsprings requiring substance A, B and C for their growth and other requiring D, E and F. If these were the only kind of offsprings we could isolate, we would conclude that probably no sexual reproduction and no exchange of genetic material had occurred. On the other hand, if such an exchange had occurred we might expect to find new kinds of offsprings.

The new kinds would be (1) bacteria requiring all six substances for growth and (2) bacteria that could synthesize all six substances. The second kind would be like the wild type; it could grow on a medium without supplements.

For Lederberg and Tatum the testing of offsprings proved rewarding. They isolated the wild type of bacteria from the mixed culture. They concluded that this

is an evidence of sexual reproduction and this is the result of some kind of genetic recombination (Fig. 5.7).

This idea was later confirmed by observations under the electron microscope. Electron microscope was used to photograph cells in mixture of two strains which could be distinguished by their structure. It was discovered that pairs of bacterial

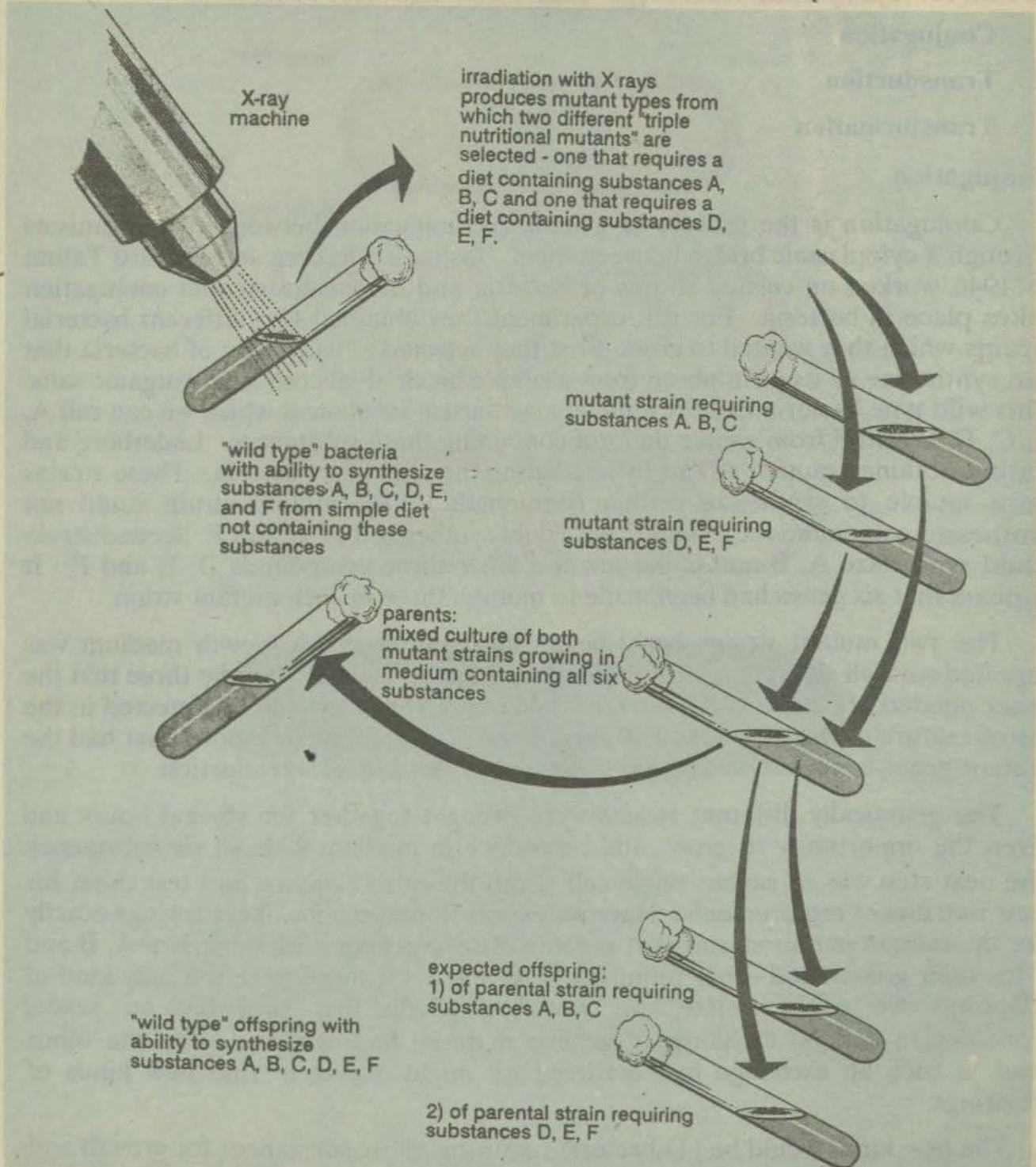


Fig. 5.7 The principal steps of the Lederberg-Tatum experiment. In what respect does the experiment offer convincing evidence that some bacteria do exchange genetic material and produce offspring with new combinations of genes?

cells, one of each type, form conjugating tubes. Transfer of genetic material takes place through these conjugating tubes (Fig. 5.8).

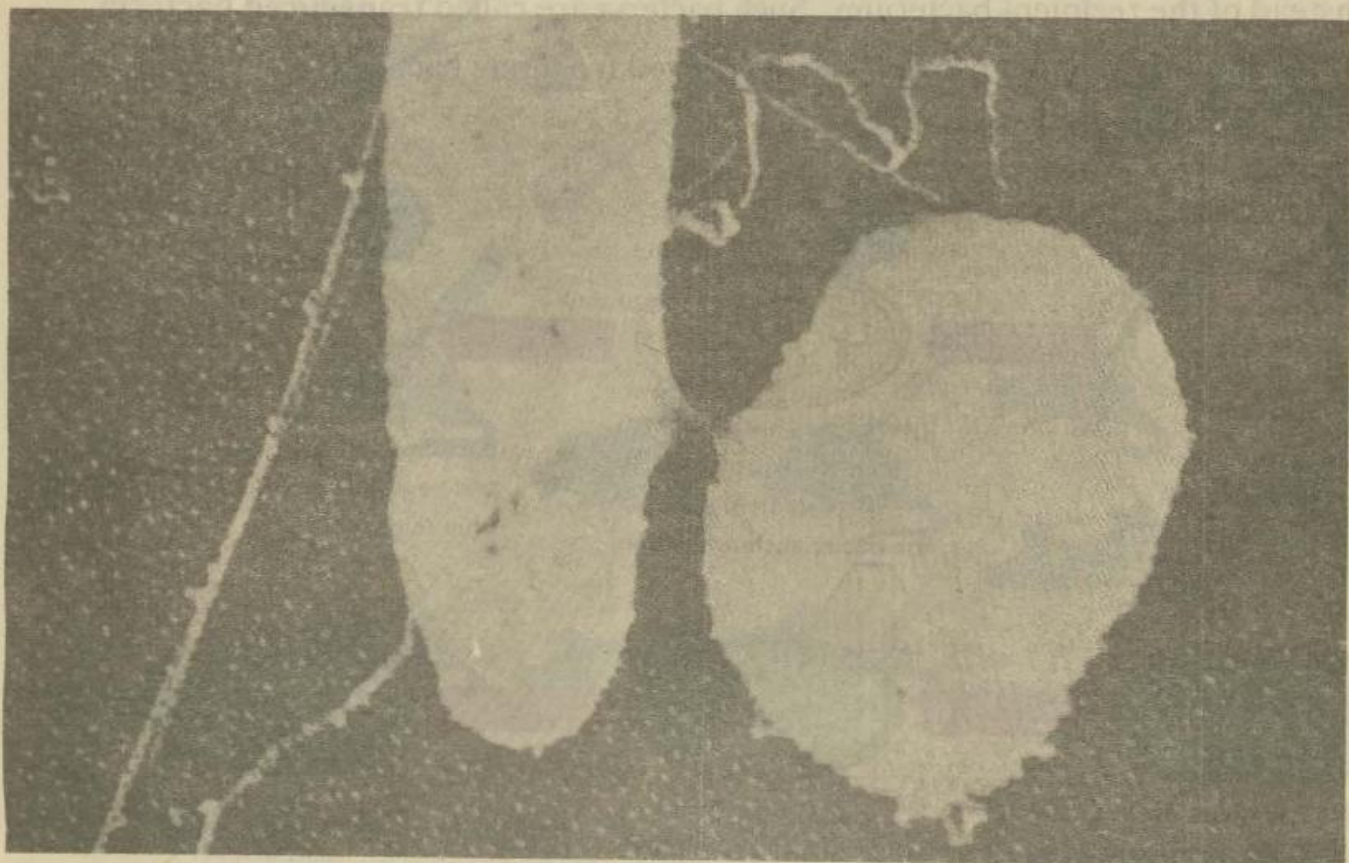


Fig. 5.8 Bacteria can exchange genetic material. This electron micrograph reveals a little tube between bacteria of two different strains, genetic material moves from one cell to the other through the tube.

Transduction

In this type of sexual reproduction genes can be transferred from one bacterium (donor bacterium) to another bacterium (recipient bacterium) by a third party, a bacteriophage. This process was discovered by Lederberg and Zinder in 1952.

When phages multiply in lytic host cell, fragments of bacterial DNA may become enclosed in the new viral coats. New phage particles destroy the host and escape out. Such host bacteria are called the **donors**. If such a new virus carrying donor bacterial DNA injects a new host cell of the same species, it will inject both viral and bacterial DNA into it. The phage virus may thus act as a vehicle for transferring genes from one bacterial cell into another of the same species. The bacterium receiving DNA from the donor via bacteriophage is called the **recipient**. The recipient bacterium is lysogenic; it is attacked by the phage but is not destroyed and host-guest relationship develops. The recipient contains three types of genetic material; that of the phage, of the donor and its own. When the recipient divides,

donor bacterial genes may be exchanged with genes of the new host and integrated into its DNA. Some of the daughter cells will receive genetic material that was derived from the donor and will have some characteristics of the donor bacterium instead of the recipient bacterium. Such bacteria are called **transduced bacteria**.

In this way genetic material may be carried from one bacterium to another by a phage virus (Fig. 5.9).

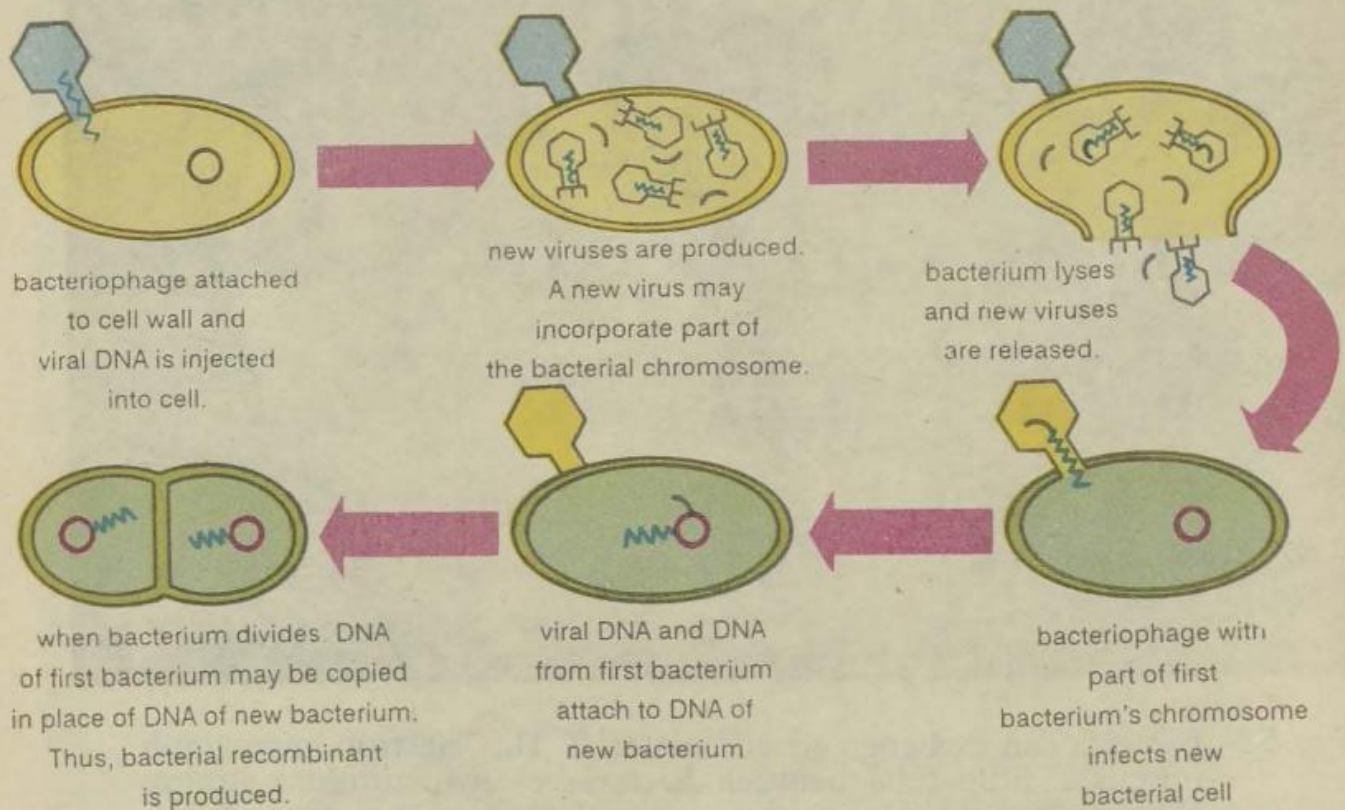


Fig. 5.9 In transduction, a portion of DNA from one bacterium is incorporated into the DNA of a second bacterium.

Transformation

Transformation is the absorption of DNA into a cell, such cells are called **transformed cells**. This DNA can be obtained from another cell or synthesized in the laboratory. Transformation is another method by which bacteria can bring about changes in their genetic material and transmit genetic information.

The evidence that bacteria can transmit genetic information came from the evidence of Avery and his co-workers (1944). They based their experiments upon those of Fred Griffith. In 1928, Griffith was studying two different strains of bacteria that cause pneumonia. One is known as smooth (S) type and is **virulent**. The other is rough (R) type and is **non-virulent**. The smooth type has a polysaccharide capsule. The rough type lacks a capsule. When Griffith injected live rough type bacteria into mice, the mice would survive. When he injected mice with live smooth type bacteria the mice died (Fig. 5.10). However, mice would survive

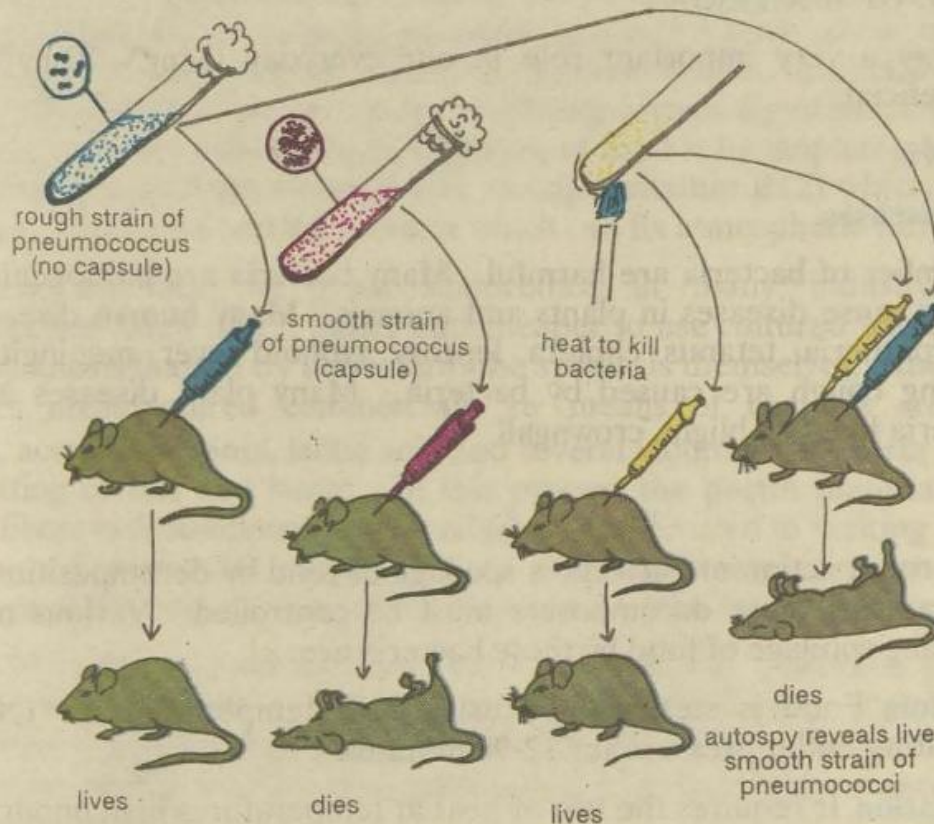


Fig. 5.10 Fred Griffiths experiment to show the transfer of genetic material.

if injected with heat killed smooth bacteria. In a crucial experiment Griffith injected mice with a mixture of live rough bacteria and heat killed smooth bacteria. Although neither of them was harmful alone, the mixture of the two caused the death of the mice. From the dead mice Griffith recovered live smooth bacteria. From these and other experiments Griffith concluded that the live rough type bacteria had been transformed into live smooth bacteria by some material from the dead smooth cells. It was possible later to carry out bacterial transformation in culture media rather than inside the bodies of mice. For example, live rough non-virulent bacteria in a test tube could be transformed into smooth virulent bacteria by the fluid in which dead virulent bacteria had been dissolved. Finally in 1944 Oswald Avery and his colleagues showed clearly that the transforming principle was DNA. It was a crucial step in the history of biology. Avery and his colleagues treated samples of the transforming principle in a variety of ways, so as to destroy different types of substances - protein, nucleic acids, carbohydrates and lipids and then tested to see whether they retained transforming activity or not. Always the answer was the same. If the DNA in the sample was destroyed, transforming activity was lost. As a final step, Avery with his coworkers isolated virtually pure DNA from a sample of pneumococcal bacteria and showed that it was highly active in causing bacterial transformation. The results were finally published in 1944, their work showed that DNA is the genetic material in cells.

IMPORTANCE OF BACTERIA

Bacteria play a very important role in our everyday living. They may be harmful or beneficial.

Harmful Bacteria

Bacteria and Diseases.

A large number of bacteria are harmful. Many bacteria are pathogenic which means that they cause diseases in plants and animals. Many human diseases like tuberculosis, diphtheria, tetanus, cholera, leprosy, typhoid fever, meningitis, sore throat, whooping cough are caused by bacteria. Many plant diseases are also caused by bacteria like fire-blight, crown gall.

Food Spoilage

Another harmful action of bacteria is spoilage of food by decomposition. Like pathogenic organisms these decomposers must be controlled. Various methods used in controlling spoilage of food by these bacteria are:

1. **Sterilization.** Food is sterilized by using high temperatures of $120-126^{\circ}\text{C}$ obtained by heating under pressure for 12-90 minutes.
2. **Pasteurization.** It requires the use of heat at temperatures high enough to kill the nonspore forming bacteria. Milk is pasteurized by heating at 71°C for 15 seconds and at 62°C for 32 minutes. With pasteurization the taste of milk is not affected.
3. **Low Temperature.** Eggs, milk, vegetables, cheese and meat can be preserved for several days by keeping them at a temperature of $10-15^{\circ}\text{C}$ for several days.
4. **Freezing.** Meats and vegetables can be frozen at below 0.0°C for several weeks to several months.
5. **Drying.** In this method the water content of food is reduced to a point at which bacteria cannot grow. Dried milk and dried meat are examples of preservation by dehydration.
6. **Preservatives.** The pH of food may be lowered by adding an acid thus inhibiting growth of microorganisms. The salt or sugar contents may be increased so that water in the food is not available to microorganisms. Chemicals like potassium metabisulphite may be added to prevent or retard the growth of microorganisms. Pickles, candies, jams and breads are preserved by such methods.
7. **Radiation.** Food may be exposed to gamma radiation, thereby destroying microorganisms and sterilizing the food. Meat, potatoes can be sterilized with this method.

Beneficial Bacteria

Bacteria have important roles in nature and in human economy as well. Most decomposers are bacteria. This process of decomposition prevents the

accumulation of dead bodies of animals, plants and metabolic wastes. It also converts materials such as nitrogen of the protein into a form usable by other living things. A large number of bacteria in our digestive system, especially in the small and large intestines are important in completing certain digestive processes. They are so important that without them, digestion of food is incomplete. Many bacteria in our intestine synthesize vitamins (for example vitamin B12) which are absorbed by the body. There are certain bacteria which can fix atmospheric nitrogen.

Bacteria are also of great importance in many industrial processes. Manufacturerees often find it easier and cheaper to use cultured bacteria in certain difficult synthesis than to try to perform the synthesis themselves. Among the many substances manufactured commercially by means of bacteria are acetic acid (vinegar), acetone, butanol, lactic acid and several vitamins. Bacteria are also used in the retting of flax and hemp. In this process the pectin material holding the cellulose fibers is decomposed and freed fibers can be used in making linens, textile and ropes. Commercial preparation of skin for making leather goods often involves use of bacteria. Curing of tobacco also involves bacteria.

Many branches of food industry depend on bacteria. Bacteria play a central role in the making of dairy products such as butter, cheese, yogurt etc. Many farmers depend on bacterial action in the making of silage for use as cattle food. There is a possibility that bacteria pathogenic to insects may eventually be used instead of insecticides.

Many bacteria are used in the production of antibiotics that can help in controlling other bacteria. Most of the antibiotics in use today are produced by various species of bacteria of actinomycetes group. Among these antibiotics are streptomycin, aureomycin, terramycin and neomycin.

CYANOBACTERIA (Blue Green Algae)

Cyanobacteria (Blue Green Algae) are the simplest of the oxygen producing photosynthetic organisms. Blue green algae closely resemble bacteria. Both blue green algae and bacteria have a very simple structure. Both are prokaryotes.

Blue green algae possess chlorophyll a and phycobilin pigment. Blue green algae can be found in almost any damp environment - in salt water and fresh water, in moist soil, on damp rocks and tree trunks. They can even grow in hot springs with temperature upto 85°C. Some of them are symbionts. Others are epiphytes. Many species are unicellular and solitary. Others form round colonies consisting of several to many cells. Still others are filamentous. Filaments are composed of cells attached end to end, like beads on a string. Being prokaryote, the blue green algae lack an organized nucleus and their genetic material is stored in a circular strand of DNA. Photosynthesis in blue green algae takes place within an extensive system of membranes located near the outer edge of cell's protoplasm. The cytoplasm contains many ribosomes. Their cell wall contains muramic acid not found in eukaryotic cell wall. The outside of cell wall is often surrounded by a protective jelly like layer or mucilaginous sheath.

About one third species of all blue green algae are able to fix atmospheric nitrogen. In most cases nitrogen fixation occurs in specialized cells called **heterocysts**. Heterocysts are enlarged cells with a unique thick envelope.

In countries like Pakistan blue green algae such as *Nostoc* and *Anabaena* are purposely cultivated in rice paddies to increase the fertility of the soil. The fertility is increased because of the ability of blue green algae to fix atmospheric nitrogen.

Sexual reproduction has not been demonstrated in blue green algae. Several types of asexual reproduction, however, do occur. These types include cell division, fragmentation, akinetes and spores. Unicellular forms reproduce by cell division. Filamentous form may fragment often at weak points next to a heterocyst. The segments that are released are called **hormogonia**. Hormogonia can produce a new filament by continued cell division.

NOSTOC - An Example of Blue Green Algae.

Nostoc is a blue green filamentous alga which is aquatic and terrestrial in habitat. It is never found in free filamentous form but occurs in colonies. The colony floats in water like a ball and is surrounded by a strong mucilaginous matrix. Mature colonies are visible to naked eye and are several centimeter thick. The individual chain of cells in a filament is called a **trichome**. Here and there in the trichome, transparent, enlarged, round or barrel shaped cells are found. These cells are known as **heterocysts**. Heterocysts may be terminal or intercalary. Each cell of the trichome has an outer peripheral zone with photosynthetic membranes and an inner central zone with nuclear material. (Fig. 5.11).

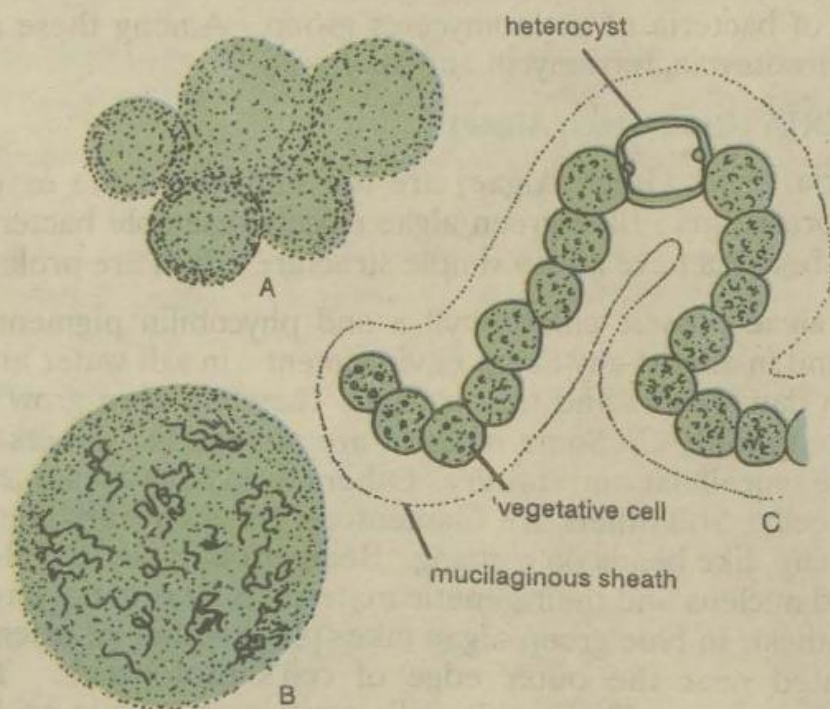


Fig. 5.11 *Nostoc* sp., A - external morphology of *Nostoc* colony; B - an enlarged dissected portion of colony and C - an enlarged filament (mucilaginous sheath is also shown).

REPRODUCTION

Nostoc reproduces asexually by the following methods. Sexual reproduction has not yet been demonstrated in blue green algae.

1. **Hormogonia.** Cells of the trichome break at the point of heterocyst. Each piece is known as hormogonium and it develops into a new trichome by cell division.
2. **Akinete.** Akinetes are enlarged cells with thickened walls, large food reserves and DNA. After a resting stage cell division occurs within the cell. Parent wall ruptures and a short filament of cells is released.
3. **Spore. Formation** Spore formation is not common. Sometime the heterocysts behave as spores and form a new plant.

QUESTIONS

1. Describe the structure of a virus. Do you think viruses are living?
2. Give the life cycle of a virus in cells of bacteria.
3. Describe the following terms:
 - a. pathogen
 - b. bacteriophage
 - c. obligate parasite
4. What is genetic recombination? How genetic recombination can take place in viruses.
5. Describe the structure of a bacterial cell.
6. a. How Gram positive and Gram negative bacteria are distinguished?
b. Write an account of nutrition in bacteria.
7. What is conjugation? Describe the process of conjugation in bacteria.
8. Describe transduction and explain how it takes place in bacteria.
9. Give an account of Griffith work on transformation.

10. How are bacteria beneficial to man?
11. Describe the harmful effects of bacteria.
12. What are the various methods used to prevent the spoilage of food.
13. List the structural characteristics of blue green algae. Where may they be found. Why blue green algae are sometime classified with bacteria in a separate kingdom Monera?
14. Describe the structure and reproduction in *Nostoc*.

FUNGI AND ALGAE

6

Fungi and algae are included by some botanists in the sub-kingdom **Thallophyta** of **Kingdom Plantae**. In thallophytes, the plant body is a **thallus**. Reproductive organs of thallophytes are unicellular and not protected by sterile cells. However many **mycologists** (who study fungi), now believe that some fungi have originated from some ancestral protozoan like flagellates and are therefore not related to plants. Fungi are therefore, segregated into a kingdom of their own which is kingdom **Fungi**. Nevertheless many biologists still include them in the plant kingdom. The group algae include aquatic photosynthesizing organisms with a thallus plant body. Algae are divided into many groups. Study of algae is called **phycology**.

FUNGI

The fungi are extremely diverse group of organisms. There are about 80,000 species in this groups. Fungi are eukaryotes. They lack chlorophyll and as such they are unable to manufacture their own food and consequently lead a saprophytic or parasitic existence. The saprophytes live on nonliving organic matter, causing it to decay; the parasites infect mostly plants or sometimes animals causing disease. The plant body is typical filamentous and is composed of thread like structures called **hyphae**. The mass of hyphae is called **mycelium**. The hyphae contain nuclei and cytoplasm and are either divided into cells by cross walls (septate) or lack cross walls (non-septate). In the majority of fungi the chief component of cell wall is chitin. Cellulose is absent in the cell wall of most fungi. True fungi are divided into following main groups:

The conjugating fungi, the water molds, the sac fungi, the club fungi and imperfect fungi. Slime molds are also commonly included in kingdom fungi. The study of fungi is called **mycology**.

Two kinds of reproduction are found in the fungi, asexual and sexual. Among the method of asexual reproduction are: (1) fragmentation in which the mycelium breaks into pieces and each fragment is capable of growing into a new individual; (2) budding, in which a small outgrowth called bud is produced as in the yeast, and

(3) spore production which is the most common type of asexual reproduction. Sexual reproduction is highly varied but always involves the fusion of two haploid nuclei and meiosis. Most fungi reproduce both sexually and asexually. Asexual reproduction is generally more important for propagation of the species. (Fig 6.1a).

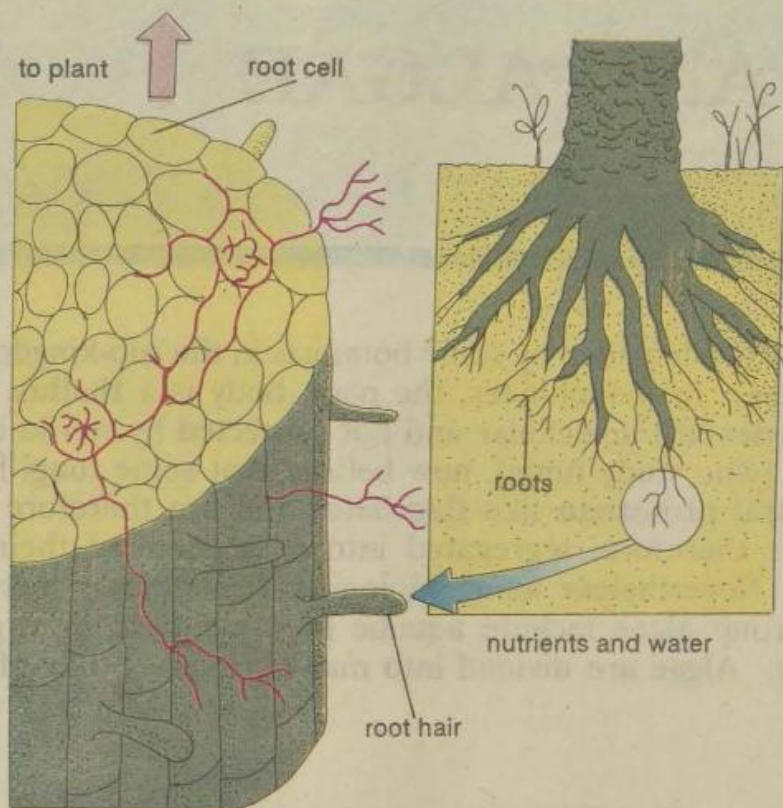


Fig. 6.1 (a) Mycorrhizae: Fungus-Root Associations.

The large majority of land plants form associations with fungi. Hyphae fan out beyond the plant's root cells and expand the surface area for absorbing water, minerals, and nutrients.

RHIZOPUS (Black Mold)

Rhizopus is the common bread mold. It is of worldwide distribution. This mold grows well on moist bread and fruits. The plant body or mycelium consists of branched hyphae. Hyphae are non septate. Each hyphae is multinucleate. It has a cell wall composed of **chitin**. Reserve food is present in the form of **glycogen**. Hyphae are of several kinds. Root like hyphae called **rhizoids** anchor the fungus, secrete digestive enzymes and absorb nutrients. Other hyphae called **stolons**, grow to form a network over the surface of the food.

The stolons give rise to still another type of hyphae that grow upward from the surface of the food. These hyphae bear **sporangium** at the tip and are called

migrate to this swelling. The central portion of the sporangium becomes separated from the peripheral zone by the deposition of the dome shaped wall. This dome shaped wall is called **columella**. Numerous spores are formed within the sporangium. The outer wall of the sporangium breaks down and spores are dispersed by air currents. On a suitable substrate spore germinates and develops into new hyphae.

Sexual Reproduction

Sexual reproduction in *Rhizopus* is by conjugation. Hyphae belonging to different strains (+ and - strains) come in close contact with one another. Tips of the hyphae are separated by septa from the rest of the hyphae. Each tip contains many nuclei with cytoplasm, mitochondria and food material. The two tips are called **gametangia**. The walls of the gametangia that are in contact dissolve away allowing the two protoplasts to fuse. The zygote resulting from this fusion develops into a **zygospore**. Zygospore has a thick wall and is quite resistant to unfavourable conditions. The zygospore will later germinate under favourable conditions. It undergoes meiosis, germinates to produce a sporangium which releases spores. Each spore can germinate and continue the life cycle.

ADAPTATION OF FUNGI FOR TERRESTRIAL MODE OF LIFE

In fungi important adaptations for terrestrial mode of life are the disappearance of flagellated cells and evolution of new methods of sexual and asexual reproduction (as in *Rhizopus*). Evolution of protective layers around spores and in some cases around zygotes and the evolution of hyphae with thickened supporting walls. Sporangioophores are the structures on which spores are produced and elevated for dispersal. Hyphae are also modified for sexual reproduction.

IMPORTANCE OF FUNGI

Fungi are both beneficial and harmful to man.

Beneficial Effects of Fungi

Fungi like bacteria, are decomposers and play an important role in nature's cycles. Beneficial fungi are of great importance commercially. Some fungi are used routinely in food production. Yeasts are used in liquor and bread production. Yeasts have also proved extremely useful in our quest of knowledge of outer space. Pink bread mold *Neurospora* has been used extensively to help us to understand the principles of inheritance. The medically important antibiotic penicillin is obtained from the genus *Penicillium*. *Penicillium* is also used in cheese production. Certain fungi are edible. These include the delicious morels and truffles. Mushrooms are of agricultural importance. About 200 species of mushrooms are edible. Some mushroom like *Amanita* are poisonous. Only an expert can distinguish the edible mushroom from the poisonous mushrooms. Mycorrhizae are fungal associations with roots of higher plants. Fungi provides certain essential elements to the plant and the plant provides food to the fungus. Such symbiotic relationship occurs in 90% of all families of higher plants.

Harmful Effects of Fungi

Fungi cause number of diseases. They can seriously damage crops. Rusts and smut diseases of wheat, rice, corn and other cereals have caused serious damage to these crops. This has resulted in displacement of hundreds of millions of humans and has caused countless deaths due to starvation. Potato blight, powdery mildew, ergot of rye, red rot of sugar-cane are some other common diseases of plants caused by fungi. In man they cause skin diseases like ringworm and athlete's foot. They also infect lungs and genital organs. Fungi cause tremendous amount of spoilage of foodstuff, timber and leather goods. Woodrotting fungi infect and destroy not only living trees but all kinds of structural timber

ALGAE

Algae are eukaryotic chlorophyllous thallophytes. Algae can be readily separated from fungi in that fungi lack chlorophyll. They can be separated from bryophytes and vascular plants in that bryophytes and vascular plants produce embryos. About 23,000 species of algae have been described. They are divided into many groups on the basis of their pigments and other features. Important groups of algae are green, brown red and golden algae. We will study *Chlamydomonas*, *Stigeoclonium* and *Ulva* as examples of algae. *Chlamydomonas* is unicellular whereas *Stigeoclonium* and *Ulva* are multicellular.

TRENDS FROM UNICELLULAR TO MULTICELLULAR ORGANIZATION IN ALGAE

It is generally believed that in the evolution of plant body one important trend is from unicellular to multicellular organization. Unicellular organisms are made up of only one cell. Multicellular organisms are made up of different kinds of cells, each kind performing specific functions. Thus multicellular organisms have certain cells modified for movement of material. Some cells provides support and some special cells are for reproduction.

Chlamydomonas is believed to represent the general type of unicellular autotroph from which multicellular green plants may have evolved long ago. At one stage in the life cycle of *Chlamydomonas* motile cells may withdraw their flagella and get attached to some object in water. Then they divide to form irregular masses of non motile green cells. This stage in the life cycle of *Chlamydomonas* can be the beginning of multicellular organization of non motile green plants.

According to one hypothesis multicellular stage originated through the aggregation of separate cells into a colony. Several surviving green algae demonstrate stages in this evolution. In these colonies of green algae we find: (1) a change from unicellular to colonial life and a tendency for the number of cells in the colony to increase; (2) the increasing coordination of activity among cells; (3) increasing interdependence among cells and (4) progressive division of labour. These characters are present in *Volvox*.

CHLAMYDOMONAS: An Example of Unicellular Green Algae

Chlamydomonas is one of the most common unicellular algae. It is found in fresh water, ponds and on damp soil. It prefers water rich in ammonia compounds. The cells are spherical to pear shaped and have a definite cellulose cell wall. There are two flagella and a well developed eye spot. Most species have a pair of contractile vacuoles near the base of the flagella. There is no central vacuole and the nucleus is more or less central in position. A single cup-shaped chloroplast occupies most of the space of the cell. In the area of the chloroplast is a red pigment body the eye spot which is sensitive to light. A pyrenoid is present in the chloroplast and is involved in the conversion of sugar into starch (Fig 6.2).

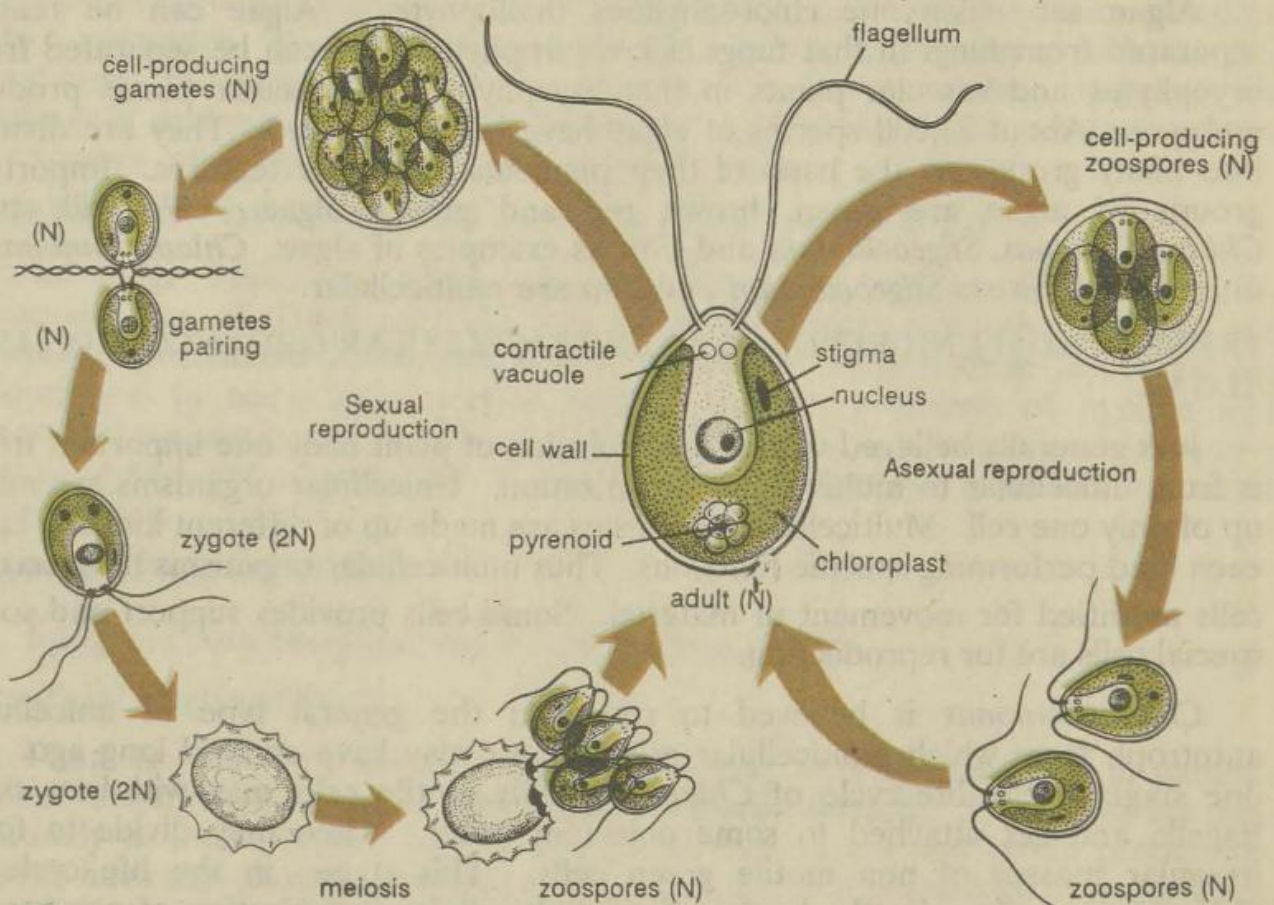


Fig. 6.2 The structure and life cycle of *Chlamydomonas* a motile green alga.

REPRODUCTION

Chlamydomonas reproduces both asexually and sexually. During asexual reproduction the cell divides into two to eight daughter protoplasts. The daughter protoplasts form cell walls and new flagella. Each daughter cell is now called **zoospore**. It is released from the parent cell, grows and swims away as a new individual.

In sexual reproduction the protoplast produces 16-32 gametes which are similar to one another. Such gametes are called **isogametes**. Gametes are also similar to vegetative cells except that they are smaller in size. The gametes fuse in pairs and form zygotes which develop thick walls and resist unfavourable environmental conditions. The zygote undergoes meiosis, forms four haploid zoospores which become mature plants when liberated.

Type of sexual reproduction in which two gametes are similar in size and structure is called **isogamy**. In addition to this isogamous reproduction, an isogamous reproduction takes place in some species. In these anisogamous species both gametes are motile but one is smaller and the other is larger. Some species of *Chlamydomonas* also exhibit oogamy. In this condition small male gamete is motile while the large female gamete is immotile. So in *Chlamydomonas* we can see the range of difference between gametes found in algae (Fig. 6.2).~

MULTICELLULAR ORGANIZATION AS ILLUSTRATED BY STIGEOCLONIUM

Stigeoclonium is a fresh water multicellular green alga distributed in lakes and streams. It grows attached to stones and vegetation. The plant consists of a prostrate portion of irregularly branched filaments which is attached to the substratum and an elongate erect branches growing out from prostrate portion, into the water. These erect branches end in hair like structures. Such a plant body is called **heterotrichous**. The cells of *Stigeoclonium* are uninucleate and contain a single girdle shaped chloroplast with one or several pyrenoids.

Reproduction is both asexual and sexual. In asexual reproduction zoospores with four flagella are liberated singly from the cells of the plant body. After a period of activity, they become attached to the substratum, secrete a wall and develop into a new plant body.

Sexual reproduction in *Stigeoclonium* is isogamous. Gametes with two or four flagella are produced in cells. Fusion of similar gametes result in the formation of a zygote. After some time the zygote loses its flagella and germinates. Meiosis takes place in the zygote and four zoospores are produced. These zoospores grow into new plants. Life cycle of *Stigeoclonium* is shown in (Fig. 6.3).

MULTICELLULAR ORGANIZATION AS ILLUSTRATED BY ULVA

Primitive green plants living in aquatic environment have evolved multicellular organization. One such alga is *Ulva*. The plant body in this alga is sheet like. It is composed of two layers of cells. Thus only the outer surfaces of the *Ulva* cells are exposed to the aquatic environment. At the base of the plant we find special cells differentiated into long threads. These cells are root like, and colourless. They are differentiated cells that perform specific function of anchorage. In *Ulva* plant we can see the division of labour.

In some *Ulva* plants tiny motile cells are produced and are released in water. These cells are similar to one another. They are gametes and they pair with one

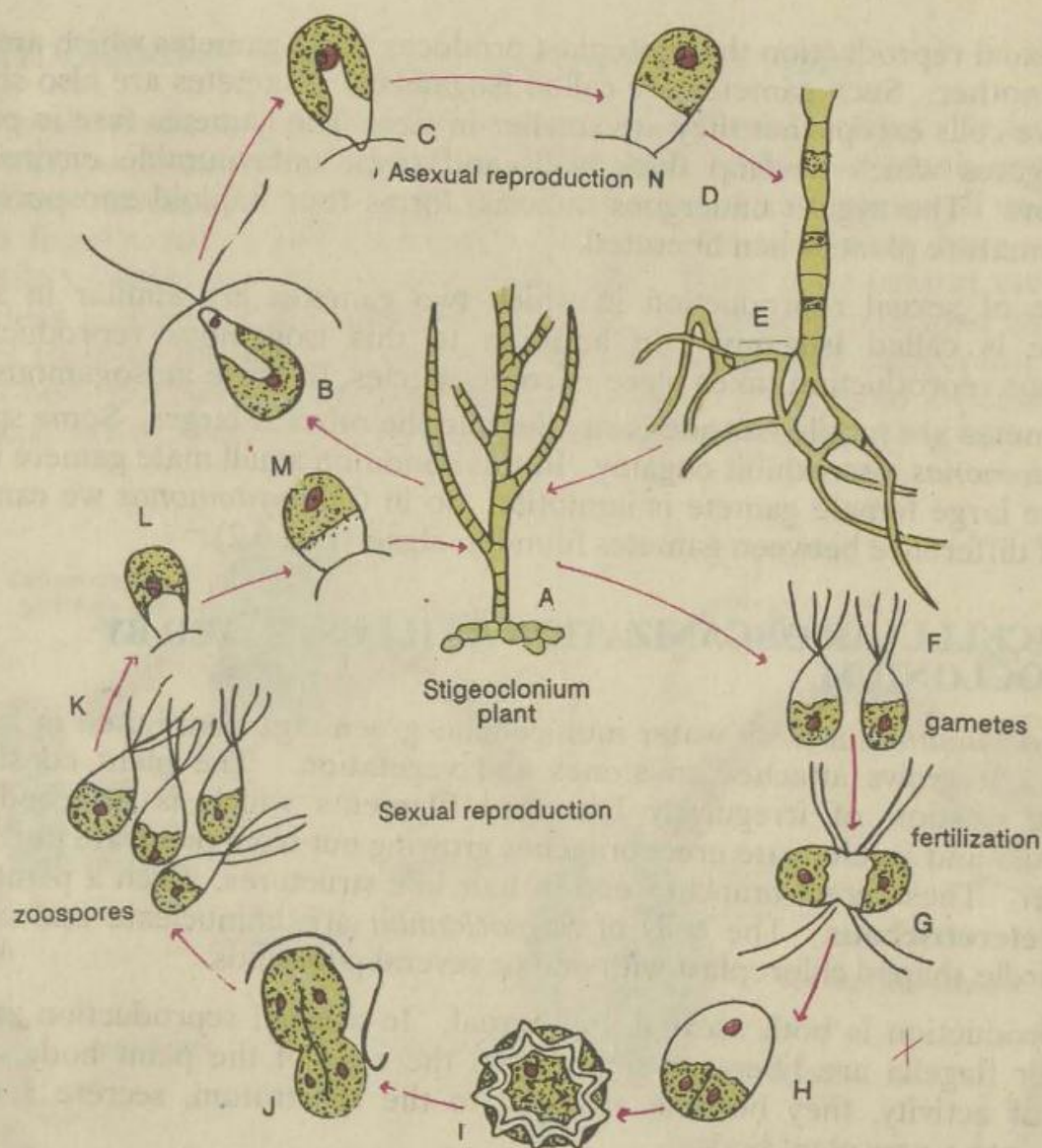


Fig. 6.3 Diagrammatic life cycle of *Stigeoclonium*.

another to form the zygote. Now these zygotes will grow into new *Ulva* plants which will have the same structure as those *Ulva* plants which produces the gametes. These new *Ulva* plants will produce motile reproductive cells which will not fuse with one another. These cells are called spores. These spores will grow into an *Ulva* plant which look exactly like the *Ulva* plant which developed from the zygote.

Alternation of Generation in *Ulva*

In the life history of *Ulva* there are two multicellular generations which look alike. One multicellular generation produces gametes and is called the **gametophyte**. The second multicellular generation produces spores and is called the **sporophyte**. So in the life history of *Ulva* the two multicellular generations alternate with each other. This phenomenon is called alternation of generations.

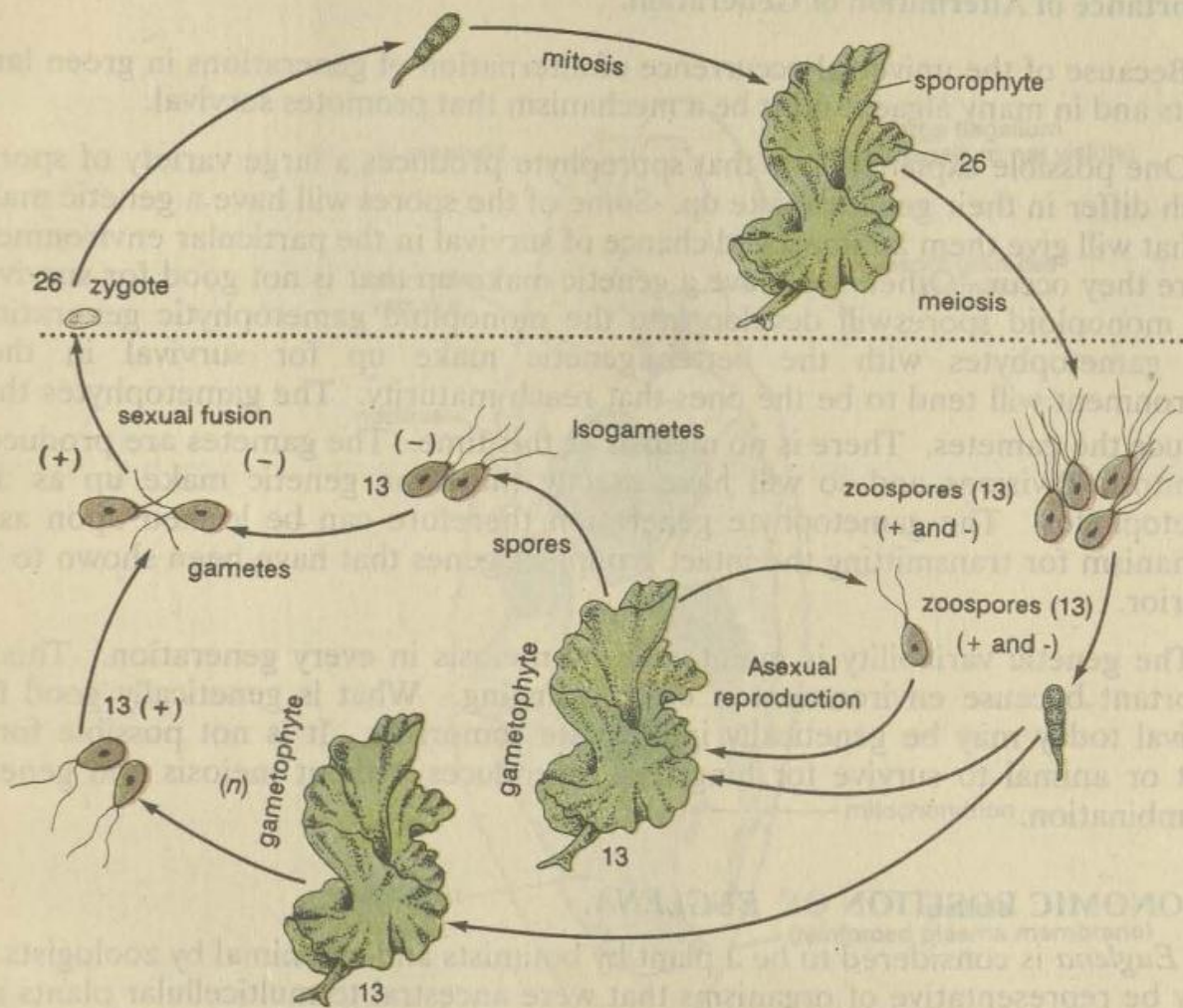


Fig. 6.4 In the life cycle of *Ulva* there is an alternation of generations of sporophyte and a gametophyte that are identical in appearance. The sporophyte produces tiny motile spores with four flagella. The gametophyte produces even smaller motile gametes that fuse with one another to form zygotes. The changes in chromosome number from one generation to the other as shown in fig. above.

When we look at the chromosome number of *Ulva* gamete we will find it to be 13. This is the monoploid or " n " number. Zygote formed by the fusion of gametes has 26 chromosomes. This is called the diploid or " $2n$ " number of chromosomes. The sporophyte plant which develops from zygote is diploid. When the spores are produced by the sporophyte, meiosis takes place and the number in spores is reduced to one half. Spores are monoploid i.e. they have 13 chromosomes. So along with alternation of generations there is also alternation of chromosome number in *Ulva*. Gametophyte is monoploid and the sporophyte is diploid.

There are several exceptions to this generalization. The life-history of *Ulva* and alternation of generation is shown in (Fig. 6.4).

Importance of Alternation of Generation.

Because of the universal occurrence of alternation of generations in green land plants and in many algae it must be a mechanism that promotes survival.

One possible explanation is that sporophyte produces a large variety of spores which differ in their genetic make up. Some of the spores will have a genetic make up that will give them an improved chance of survival in the particular environment where they occur. Others will have a genetic make up that is not good for survival. The monoploid spores will develop into the monoploid gametophytic generation. The gametophytes with the better genetic make up for survival in their environment will tend to be the ones that reach maturity. The gametophytes then produce the gametes. There is no meiosis at this time. The gametes are produced by mitotic divisions and so will have exactly the same genetic make up as the gametophytes. The gametophyte generation therefore can be looked upon as a mechanism for transmitting the intact groups of genes that have been shown to be superior.

The genetic variability is maintained by meiosis in every generation. This is important because environment is often changing. What is genetically good for survival today may be genetically inadequate tomorrow. It is not possible for a plant or animal to survive for long if it reproduces without meiosis and genetic recombination.

TAXONOMIC POSITION OF *EUGLENA*.

Euglena is considered to be a plant by botanists and an animal by zoologists. It may be representative of organisms that were ancestral to multicellular plants and animals. *Euglena* is a flagellated organism with no cell wall (Fig. 6.5). *Euglena* shows a combination of plant like and animal like characteristics. It is plant like in that it has chloroplasts and chlorophyll and is photosynthetic. *Euglena* is animal like in that it lacks a cell wall and is motile. Some biologists have segregated such organisms into a separate kingdom, the **Protista**.

It is known that some of these autotrophs under experimental conditions lose their chlorophyll. If *Euglena* is grown in the dark it loses its chlorophyll and this does not result in its death. It starts living like an animal by ingesting the food and also absorbing soluble nutrients. So *Euglena* is capable of functioning both as a heterotroph (in the absence of light) and as an autotroph (in the presence of light). A unicellular organism with the potentialities of *Euglena* deserves special attention when we are searching for the kind of organism that might represent the ancestral type from which plants and animals might have evolved in the distant past.

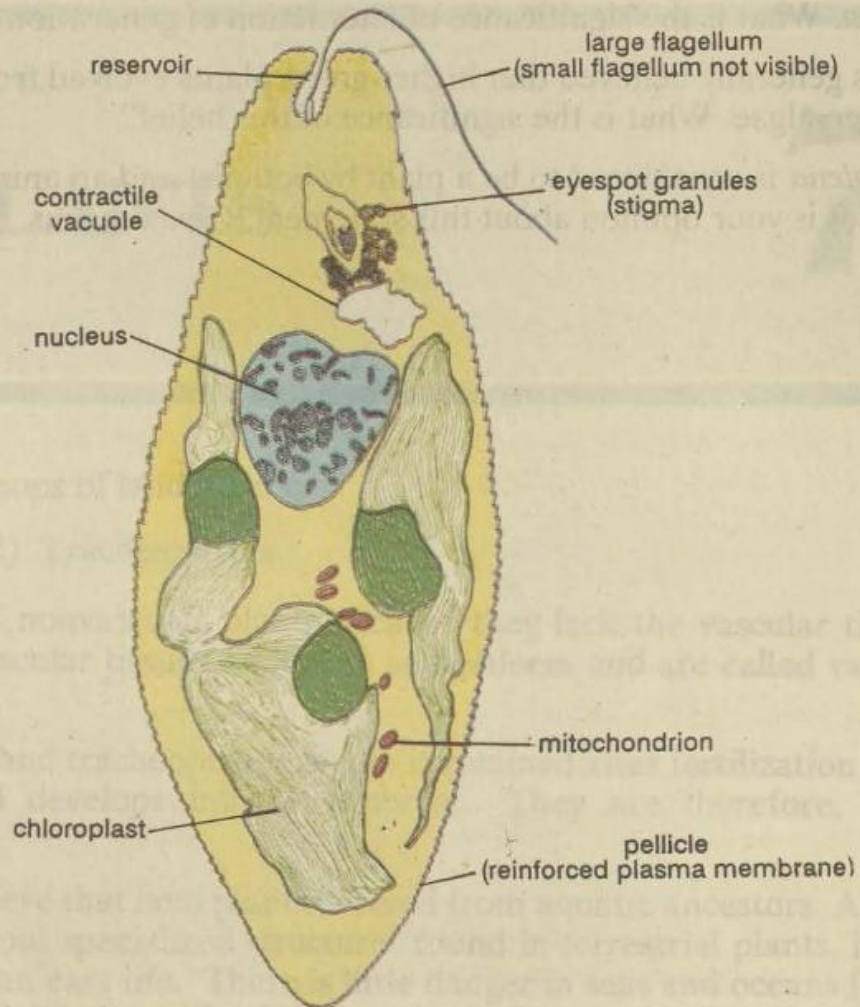


Fig. 6.5 *Euglena*: A typical protist.

QUESTIONS

1. Some biologists include fungi in a separate kingdom. What is the reason for this?
2. Give an account of the structure and reproduction of *Rhizopus*.
3. How are fungi adapted for life on land?
4. Write an essay on the importance of fungi.
5. Describe the structure and reproduction in *Chlamydomonas*.
6. Explain the trend from unicellular to multicellular organisms in plants.

7. Give an account of structure and reproduction in *Stigeoclonium*.
8. What is alternation of generation? Explain with reference to the life history of *Ulva*. What is the significance of alternation of generation?
9. It is generally believed that higher green plants evolved from *Stigeoclonium* like green algae. What is the significance of this belief?
10. *Euglena* is considered to be a plant by botanist and an animal by zoologist. What is your opinion about this statement? Give reasons.

LAND PLANTS

7

There are two groups of land plants:

1- **Bryophytes** and (2) **Tracheophytes**

Bryophytes are the nonvascular plants because they lack the vascular tissues. Tracheophytes have vascular tissues i.e. **xylem** and **phloem** and are called vascular plants.

In both bryophytes and tracheophytes zygote is retained after fertilization in the female sex organ and develops into an embryo. They are therefore, called **embryophytes**.

Most biologists believe that land plants evolved from aquatic ancestors. Aquatic plants can survive without specialized structures found in terrestrial plants. Life of an aquatic organism is an easy life. There is little danger in seas and oceans for any lack of water so essential for growth of living things. There are abundant carbon containing compounds in solutions that are used by photosynthetic organisms. These photosynthetic organisms in turn provide a continual supply of oxygen for all living things in the sea. The temperature in the vast bodies of water does not fluctuate so much as the temperature on land. In short the aquatic environment of the ocean, seas or any large permanent body of water is much more uniform and much better supplied than is the rigorous land environments.

BRYOPHYTES (NON VASCULAR PLANTS) **LIVER WORTS & MOSSES**

Bryophytes include the **liverworts** and **mosses**. One example of a liverwort is *Marchantia* and of a moss is *Funaria*. The size of plants of this group remained small. They are restricted to those places where there is abundance of water. Water is needed for their sexual reproduction. Bryophytes are sometime called amphibious plants. This is because of their dependence on water.

Let us now study some of the features shown by bryophytes for life on land.

Adaptive Characters Exhibited by Bryophytes for Life on Land

Bryophytes show a number of adaptations for life on land.

These adaptations are as follows:

1. Multicellular Plant Body and Conservation of Water

Land plants have faced the potential danger of dehydration due to evaporation, as they migrated from water environments. A multicellular organism like liverwort, *Marchantia*, has number of features which prevent the loss of water from the surface. In a cross section of *Marchantia* thallus (Fig. 7.1), we can see that it is

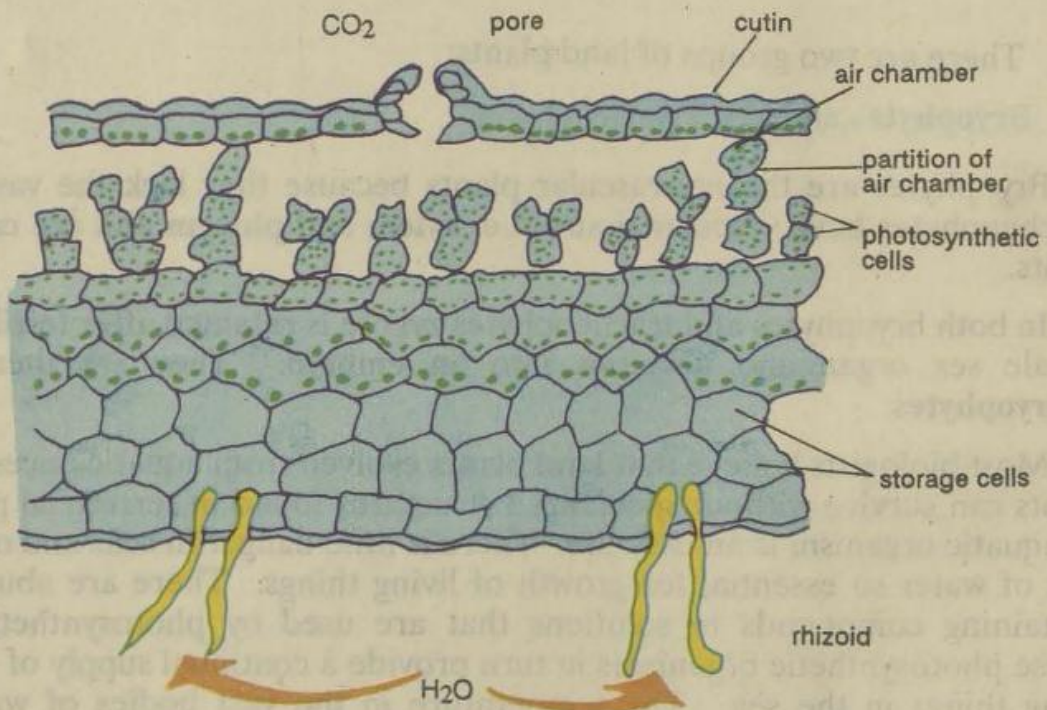


Fig. 7.1 A drawing of part of a sectioned *Marchantia thallus*. How do the rhizoids and the layer of cutin affect survival of the plant on land?

many cells thick. Of all the cells comprising the thallus only a small percentage have cells directly exposed to the drying effect of the environment. Further reducing the rate of evaporation from surface cells is the formation of a waxy layer called **cuticle** on **epidermis**. In most bryophytes this layer is made up of water proof material called **cutin**.

2. Absorption of Carbon Dioxide

Unlike aquatic plants which obtain and excrete gases dissolved in water, land plants require an efficient means to exchange gases with environments. The upper epidermis of bryophytes is provided with numerous pores for the diffusion of carbon dioxide and oxygen. Because of the branching nature of inner structure of thallus the cells present a tremendous amount of wet surface available for absorption of carbon dioxide. At the same time evaporation of water can occur from the wet surfaces of these cells. Thus, while absorbing carbon dioxide from the atmosphere the green land plants will lose much needed water. The evaporating water must be replaced or *Marchantia* will soon wilt or die.

3. Absorption of Water

On the underside of the thallus of *Marchantia* there are special structures called **rhizoids**. These rhizoids are present in other bryophytes also. Rhizoids are long filamentous extensions of the cells of the lower epidermis. They greatly increase the surface for absorption of water from the soil. Rhizoids perform the same functions as do the water absorbing roots and the root hairs of vascular plants.

4. Heterogamy

The universal occurrence of **heterogamous** type of sexual reproduction in green land plants and animals leaves little doubt that it is the most successful type of reproduction to evolve. The large nonmotile egg formed in heterogamy is full of stored food. After fertilization this stored food is used to nourish the early stages in the development of the new offspring. In other kinds of sexual reproduction for example, isogamy, the supply of stored food contributed even by the two gametes together is very small.

5. Protection of Reproductive Cells

The protection of reproductive cells i.e, sperm and egg from mechanical injury is a very important characteristic of green land plants. The sex organs of a moss plant are located at the tips of the green shoot. There are two types of sex organs. In male sex organ called **antheridium** sperms are produced and in the female sex organ called **archegonium** egg is produced.

Both types of sex organs are multicellular. In this way, they differ from algae where the sex organs are unicellular. Most of the cells of the moss sex organs are sterile. They form a protective covering around the sperm and the egg. Drying of the sex organs is prevented by sterile hairs which are produced in between the sex organs. The sex organs are also protected by leaf-like structures which surround the sex organs (Fig 7.2).

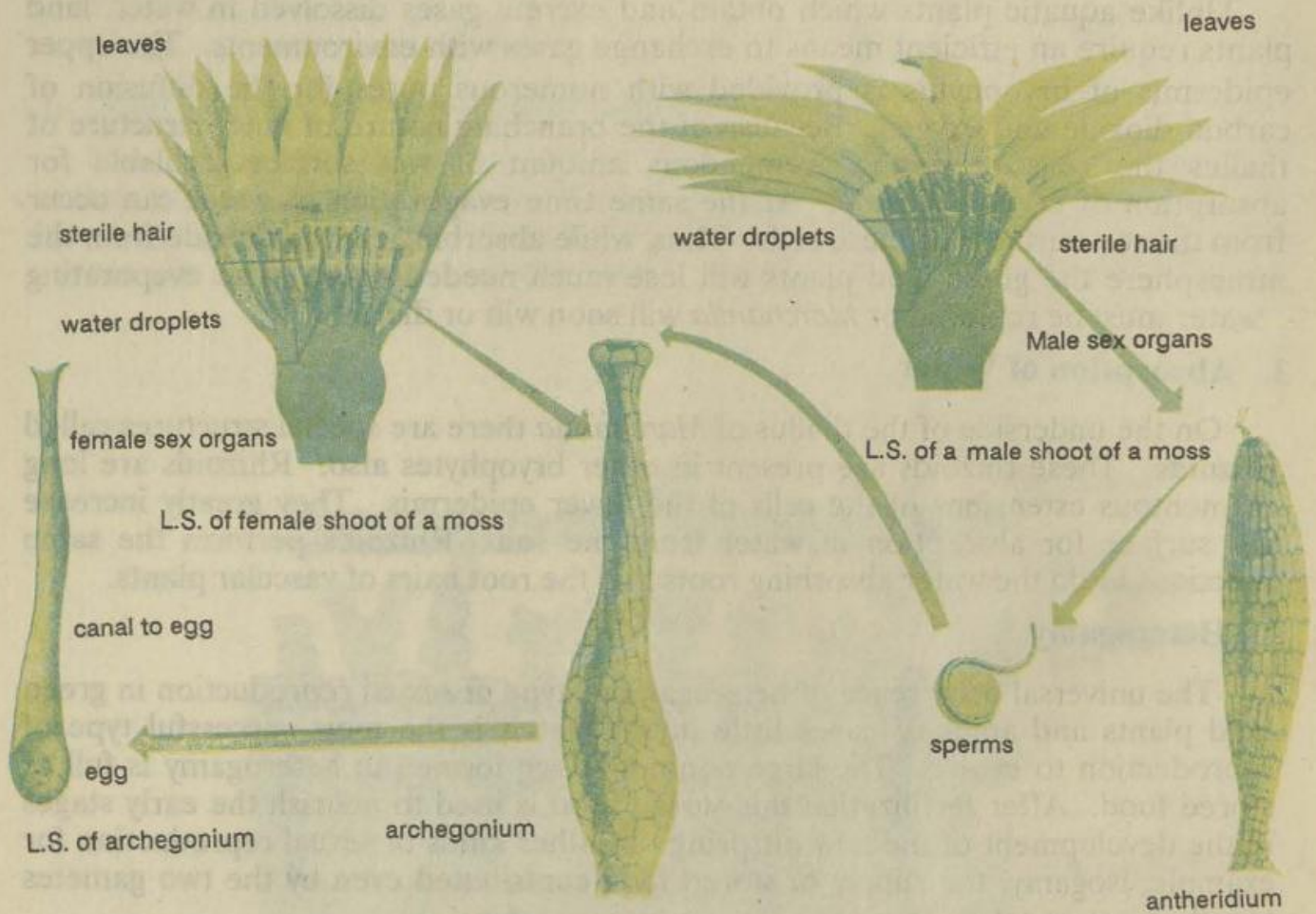


Fig. 7.2 Sex organs of a Moss

6. Embryo Formation

In the moss plant zygote after its formation is retained in the female sex organ. This zygote divides inside archegonium and forms an embryo. The embryo is protected by the wall of the archegonium. In this way, chances of survival are increased. Embryos are present in all bryophytes and vascular plants.

7. Alternation of Generations

The life cycles of all land plants show an alternation of generations. We can see this phenomenon clearly in a moss plant (Fig. 7.3).

In the life history of a moss the two generations, **gametophyte** and the **sporophyte** are quite different in their structure and physiology. The gametophyte is the dominant generation. It produces the sex cells, sperm and the egg in the sex

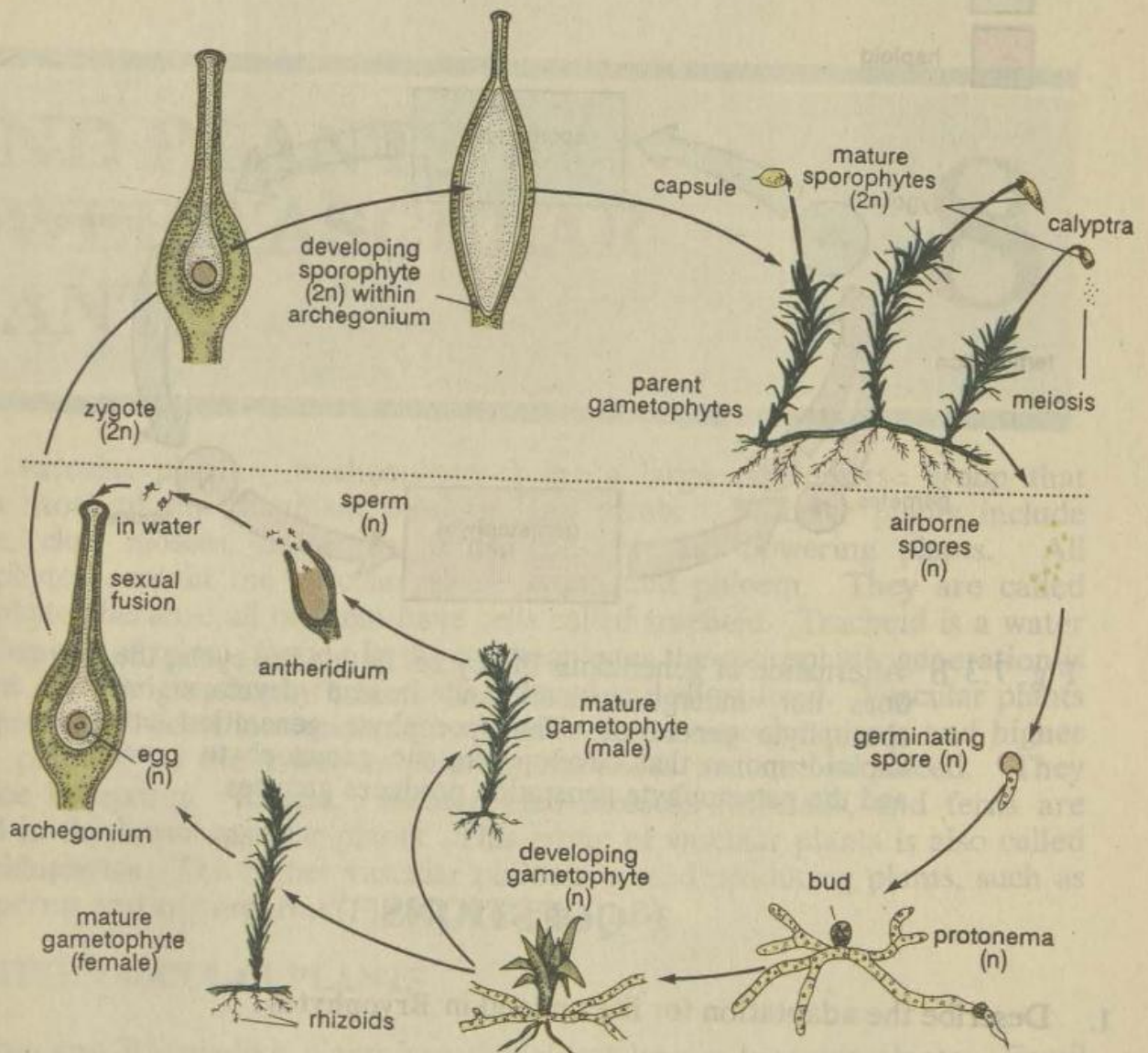


Fig. 7.3 a Generalized life cycle of a Moss.

organs, antheridium and archegonium. The zygote which is formed by the fusion of sex cells develops into an embryo. From this embryo a sporophyte is produced. This sporophyte consists of a foot, stalk and a capsule. The sporophyte is dependent on the gametophyte for its food and water etc. The foot of the sporophytes absorbs food from the gametophyte. The stalk elevates the capsule. Inside the capsule spores are produced by meiosis. These spores are dispersed and they form the gametophyte. Alternation of generations increases the chance of survival of land plants.

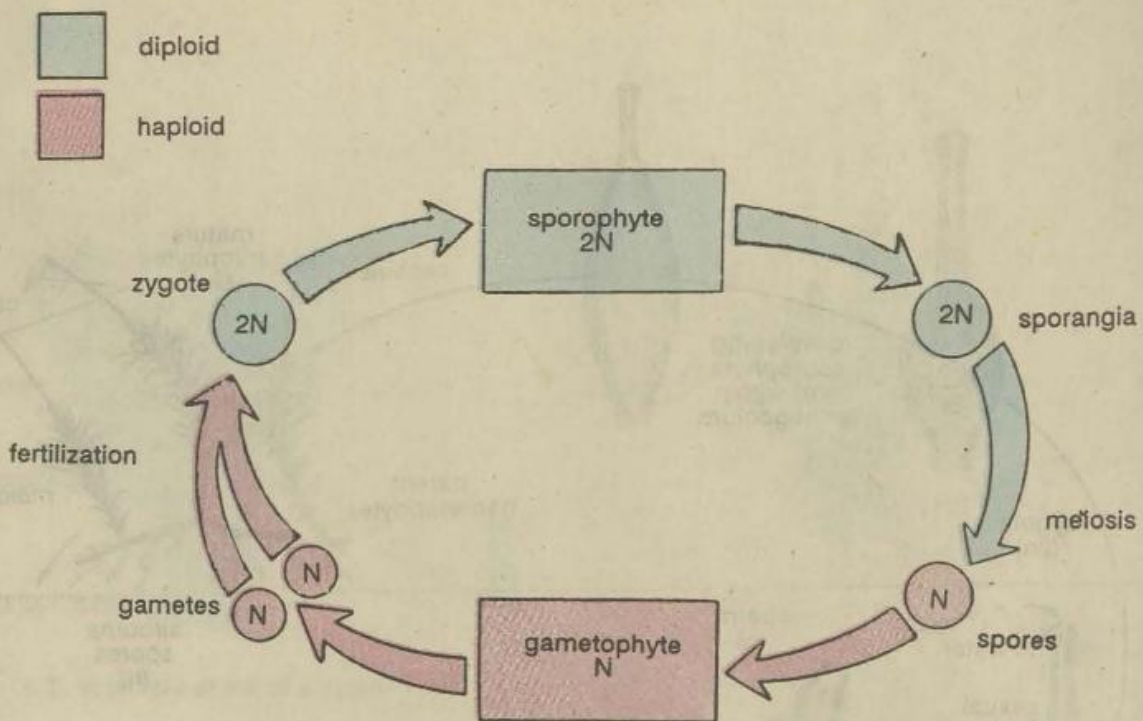


Fig. 7.3 b Alternation of generations life cycle. In this life cycle, the zygote does not undergo meiosis and instead develops into the sporophyte generation. The sporophyte generation produces haploid spores that develop into the gametophyte generation and the gametophyte generation produces gametes.

QUESTIONS

1. Describe the adaptation for life on land in **Bryophytes**.
2. What is alternation of generation. Explain with reference to the life history of moss. How alternation of generation in a moss is different from that of an *Ulva*.
3. Draw the diagram of the cross section of thallus of *Marchantia*.

LAND PLANTS

LOWER VASCULAR PLANTS

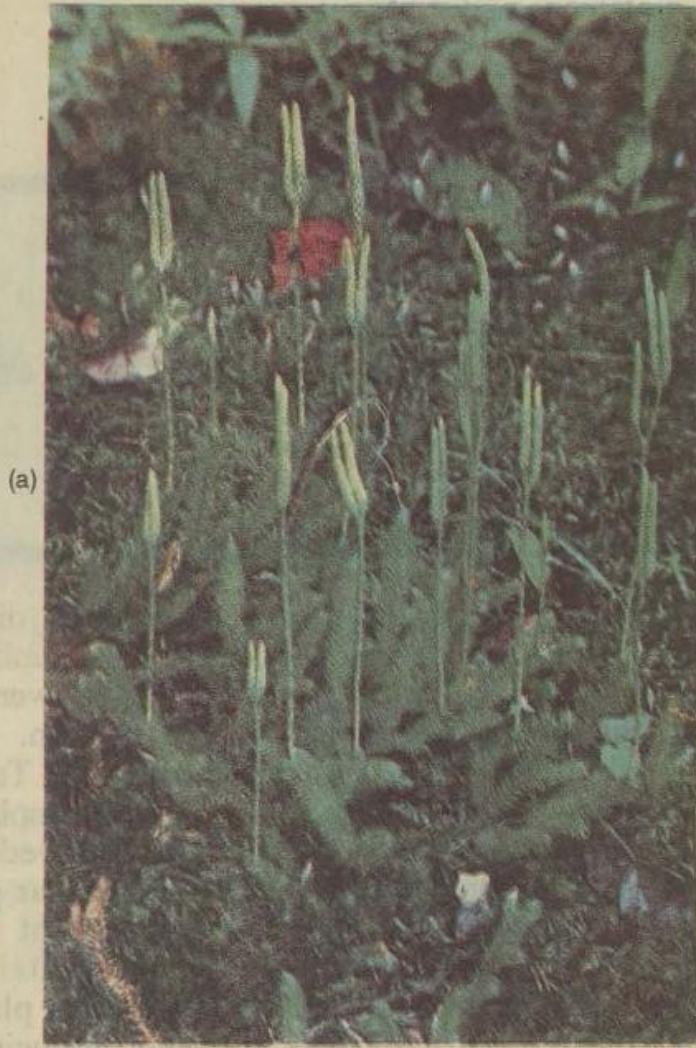
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The vascular plants (tracheophytes) are a large and diverse group that includes most of the dominant modern land plants. Vascular plants include *Psilotum*, club mosses, horsetails, ferns, conifers and flowering plants. All tracheophytes contain the vascular tissue xylem and phloem. They are called tracheophytes because all of them have cells called **tracheid**. Tracheid is a water conducting cell of xylem tissue. In the tracheophytes the sporophytic generation is dominant and the gametophyte is small, reduced and short lived. Vascular plants can be broadly divided into major sub-divisions, lower vascular plants and higher vascular plants. In the lower vascular plants seeds are not produced. They reproduce by spores, *Rhynia*, *Psilotum*, club mosses, horsetails, and ferns are included in the lower vascular plants. This group of vascular plants is also called the **pteridophytes**. The higher vascular plants are seed producing plants, such as gymnosperms and angiosperms (Fig 8.1 A & Fig 8.1 B).

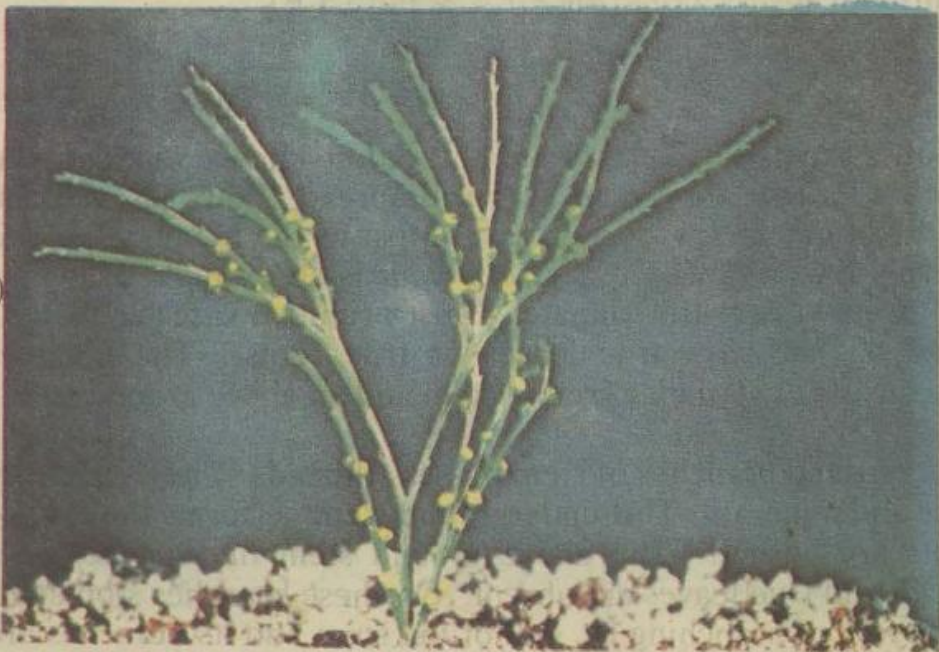
PRIMITIVE VASCULAR PLANTS

Rhynia and *Rhynia*-like plants are the oldest known vascular plants. Fossil evidence indicates that this group was widespread about 400 million years ago. *Rhynia* is a fossil member of this group. Most of the members of this group are extinct but only few are living today. *Psilotum* is an example of living member of this group. It grows in warm climate. Most primitive vascular plants like *Rhynia* and *Psilotum* do not have true leaves or true roots. The plant body of the sporophyte consists of an under ground stem and an above ground stem (Fig 8.2).

The underground branches of stem possess rhizoids. They anchor the plant and absorb water and minerals. This underground stem performs the function of a root as true roots are absent. The above ground stem or branches are green and photosynthetic and true leaves are absent. On these branches stomata can be seen. The stem has forked branching i.e. end of the stem and its branches are Y-shaped. In a cross section of the stem we can see the internal structure. Its structure is very simple. There is an outermost layer of **epidermis**, a **cortex** of thin walled cells and a small or narrow central cylinder of **vascular tissue**. The xylem is present in the



(a)



(b)

Fig. 8.1 A Representative lower tracheophytes. These plants were widespread when the tracheophytes first evolved. a. *Lycopodium* (Club Mosses). b. *Psilotum*.

(a)



(b)

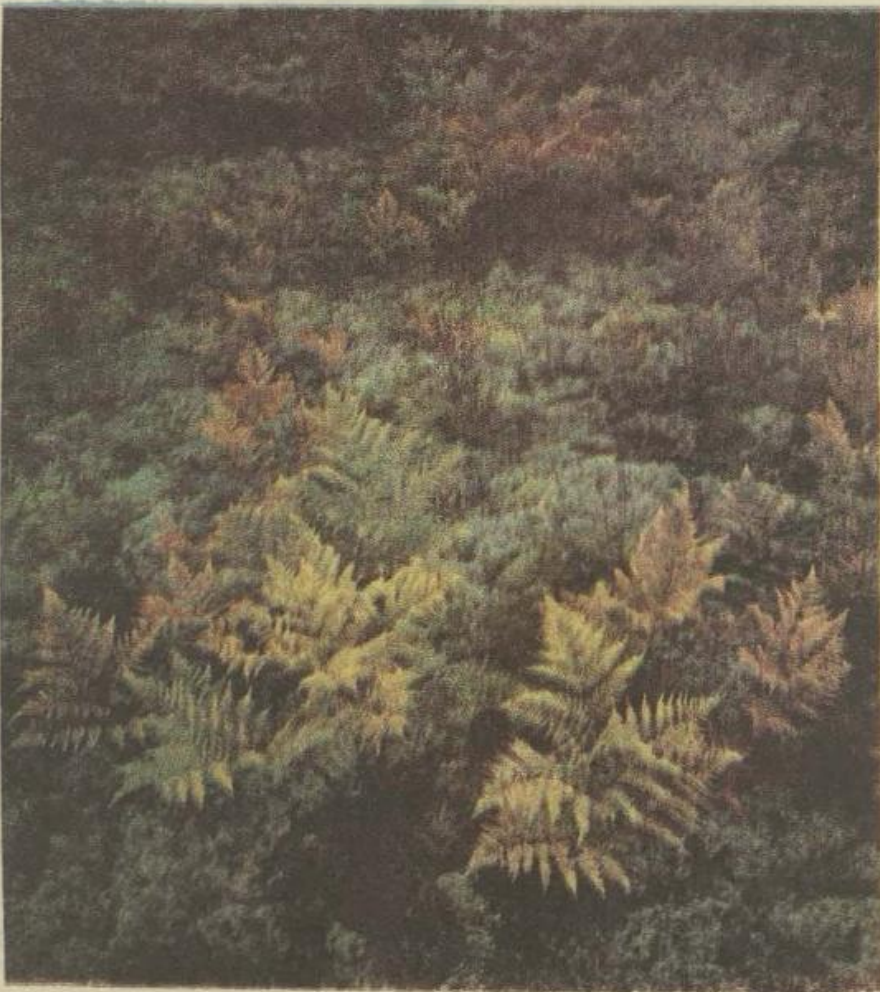


Fig. 8.1 B Representative fern *a*. The undersides of the large fronds are covered with sori, clusters of tiny sporangia. *b*. The sporophyte generation of a bracket fern.

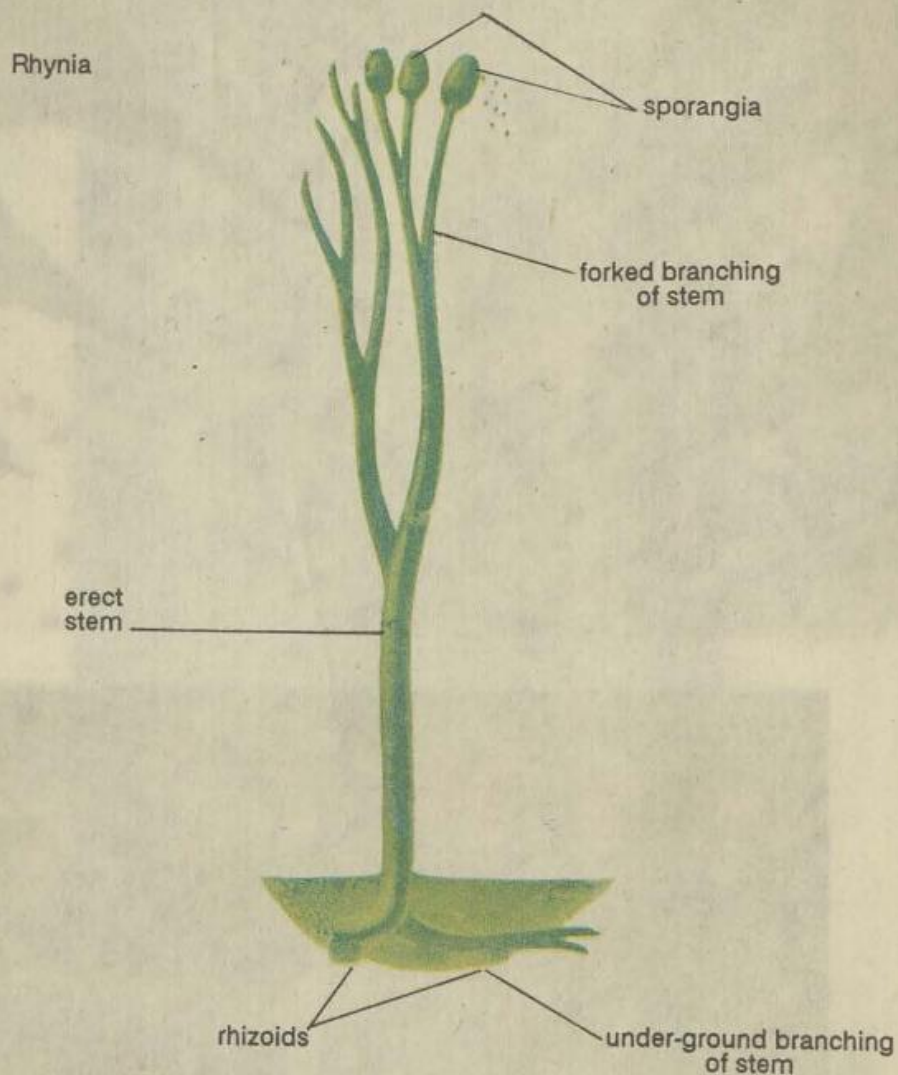


Fig. 8.2 *Rhynia major*, one of the earliest vascular plants. They lived 365 to 400 million years ago. The sporophyte of *Rhynia major* illustrated here had erect photosynthetic stems that terminated with a sporangium. It lacked leaves and roots, attaching itself to the ground by rhizoids.

centre and is surrounded by phloem. Sporangia are produced at the tip of some branches. Inside the sporangia thick walled spores are produced.

Psilotum is an example of living members of the group we have just studied. *Psilotum* also lacks true leaves and roots and the stem has forked branching. Arrangement of vascular system is simple i.e. it has xylem in the centre which is surrounded by phloem. Sporangia are found at the tips of much reduced branches (Fig. 8.3).

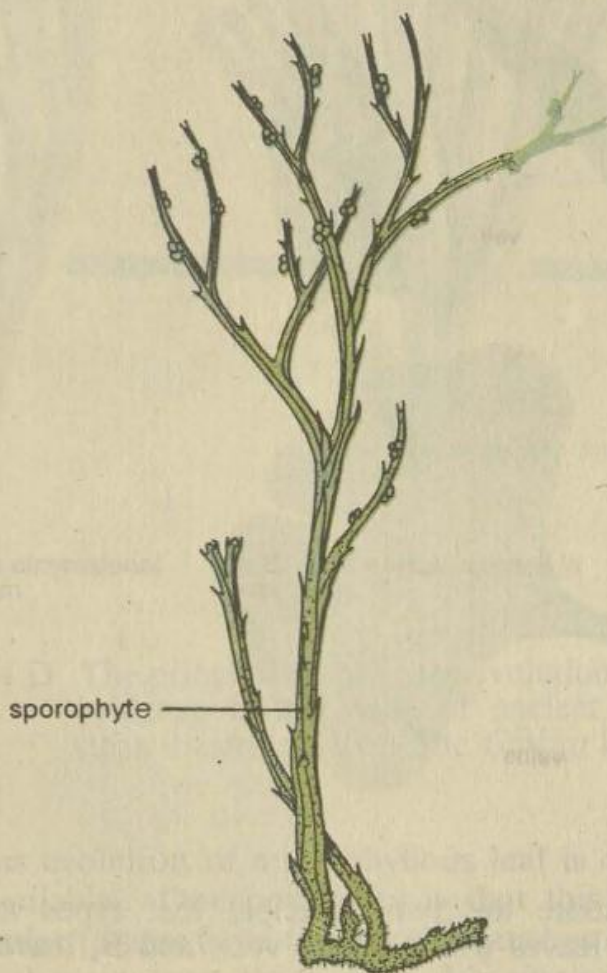


Fig. 8.3 *Psilotum*-Plant body

The characters we have seen in *Rhynia* and *Psilotum* were the characteristics of the most primitive vascular plants. All other vascular plants i.e. club mosses, horsetails, ferns, gymnosperms and angiosperms evolved from such primitive vascular plants starting about 400 million years ago.

EVOLUTION OF LEAF

Leaf is an important organ present in all the vascular plants which evolved from the primitive vascular plants. There are two main types of leaves in vascular plants. One type of leaf is simple, small and scale like. It has a single vein or vascular bundle and therefore, it is called one veined-leaf or **microphyllous** leaf. Microphyllous leaves are present in club mosses and horsetails. The other type of leaf is called many veined leaf or **megaphyllous** leaf. This type of leaf is large and has a prominent blade with many veins (Fig. 8.4 A & Fig. 8.4 B).

A. Leaf of
Lycopodium



B. Leaf of *Ginkgo*

Fig. 8.4 These leaves illustrate the two principal leaf types among vascular plants: A, leaves with a single vein, and B, leaves with many veins.

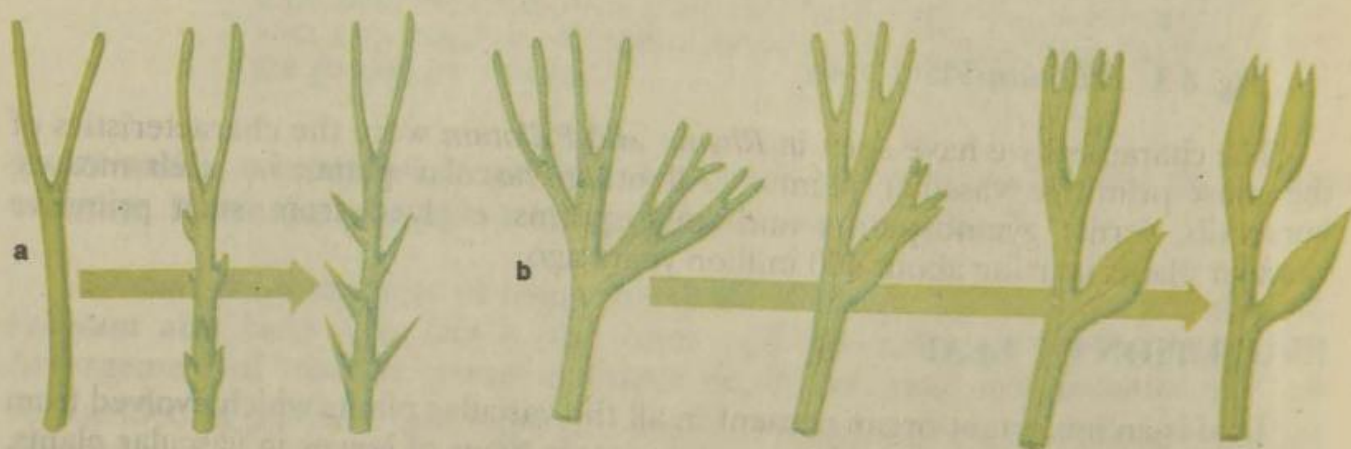
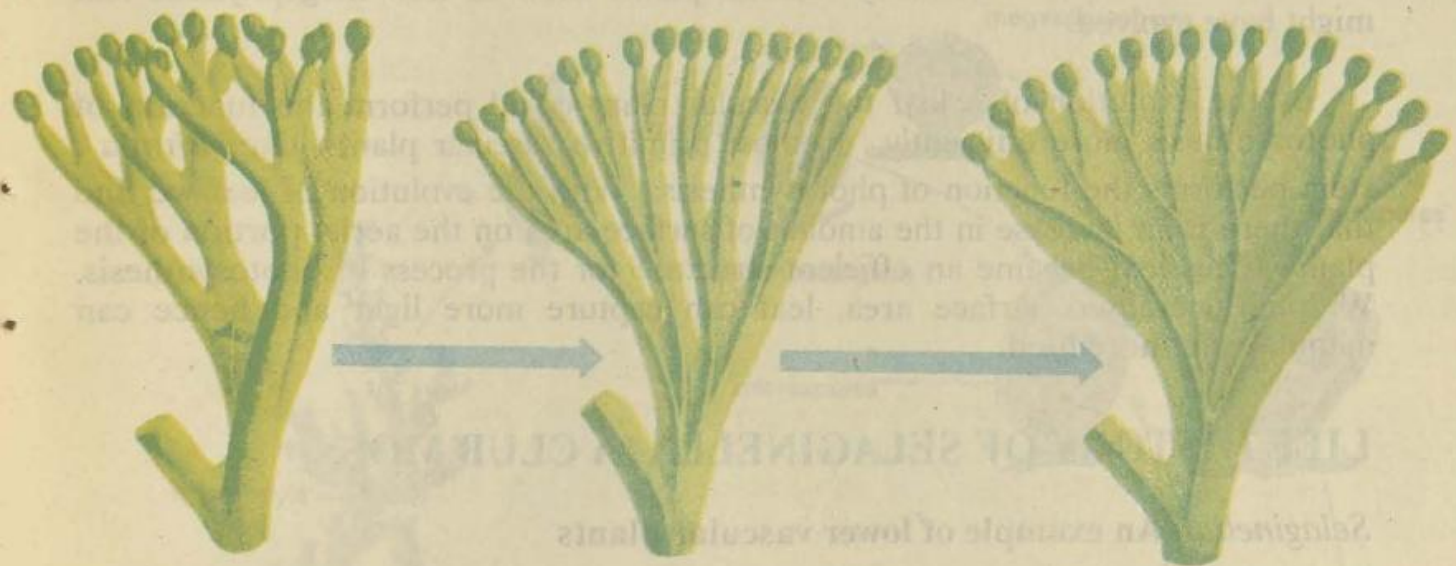


Fig. 8.4 C A diagrammatic summary of two different theories of the evolution of single-veined leaves. Whether leaves emerged from naked branches, as in a, or resulted from a reduction of branches, as in b, tens or even hundreds of thousands of plant generations must have been required for the evolution to take place.



a Primitive three dimensional branching system.

b Branches are all aligned in one plane.

c Areas between branches become filled with tissue.

Fig. 8.4 D The principal steps in the evolution of a many-veined leaf. Much evidence from fossils of ancient vascular plants supports the steps illustrated here. The *Ginkgo* leaf (Fig. 8.4 B)

As far as evolution of microphyllous leaf is concerned we have no clear fossil evidence available. One possibility is that this leaf originated as an outgrowth, lacking vascular tissues from the naked branches of the primitive plant (Fig 8.4 C,a). Later when these outgrowths increased in size a need for support and transport of material arose and vascular tissue was provided to the leaf.

The second possibility proposes that in the leafless branching system of early vascular plants, there was a gradual reduction in size of portion of a branch. In this way, by simplification and reduction in size of a portion of leafless branching system, a one veined leaf evolved. This second possibility is shown in (Fig 8.4 C,b).

The second type of leaf or megaphyllous leaf is considered to be an evolutionary modification of the forked branching system found in *Rhynia* and other early land plants. The first step in the evolution of these leaves was the restriction of forked branching to a single plane.

The branching system became flat. This first step in the evolution is called **planation**. Next in evolution the space between the bundles and branches of the vascular tissue became filled with photosynthetic tissue. This is called **webbing**. After this the organ, now a leaf, looked superficially like the webbed foot of a duck (Fig 8.4 D)..

The fossils remains of many vascular plants show us how megaphyllous leaf might have evolved.

By the evolution of a leaf the vascular plant could perform the function of photosynthesis more efficiently. In most primitive vascular plants, like *Rhynia*, stem performs the function of photosynthesis. With the evolution of leaf we find that there is an increase in the amount of surface area on the aerial portion of the plant. Thus leaf became an efficient structure for the process of photosynthesis. With an increased surface area, leaf can capture more light and hence can manufacture more food.

LIFE HISTORY OF SELAGINELLA (A CLUB MOSS)

Selaginella - An example of lower vascular plants

Selaginella is a large genus containing approximately 700 species. It is widely distributed. Most of the species are tropical. Some are found in the temperate zone. In northern areas of Pakistan some species of *Selaginella* have been reported.

Plant body of *Selaginella* is sporophyte. It consists of a branched prostrate stem with upright branches. Both horizontal and upright stems are covered with small leaves in four longitudinal rows. There are two rows of small leaves and two rows of large leaves. In some species, all leaves are of the same size. At the base of each leaf projecting from its upper surface is a small leaf like outgrowth called the **ligule**. Roots are produced from leafless branches or **rhizophores** which grow from the stem into the ground and bear adventitious roots. The vascular system of the stem consists of a core of xylem surrounded by phloem. There is no cambium.

At the ends of the upright branches reproductive leaves or **sporophylls** are produced. These sporophylls are grouped to form cones or **strobili**. Sporangia grow in the axils of sporophylls. Two types of sporangia are present in *Selaginella*: the **microsporangia** in which small microspores are produced and **megasporeangia** in which large megaspores are produced. A single cone usually contains both kinds of sporangia and thus produces both types of spores (Fig. 8.5).

In a developing megasporangium only one megaspore mother cell remains and it divides by meiosis to form four large thick walled megaspores. Each megaspore is capable of giving rise to female gametophyte. In a microsporangium many small spores, the microspores are formed by meiosis. All microspores are capable of developing into male gametophyte. Production of two types of spores is called **heterospory**. Repeated mitotic cell divisions of the megaspore result in the formation of the female gametophyte within the megaspore cell wall. The megaspore may be shed from the strobilus at any stage in the development of the female gametophyte (**megagametophyte**) or may remain in the strobilus after fertilization until the completion of early embryonic development. The material

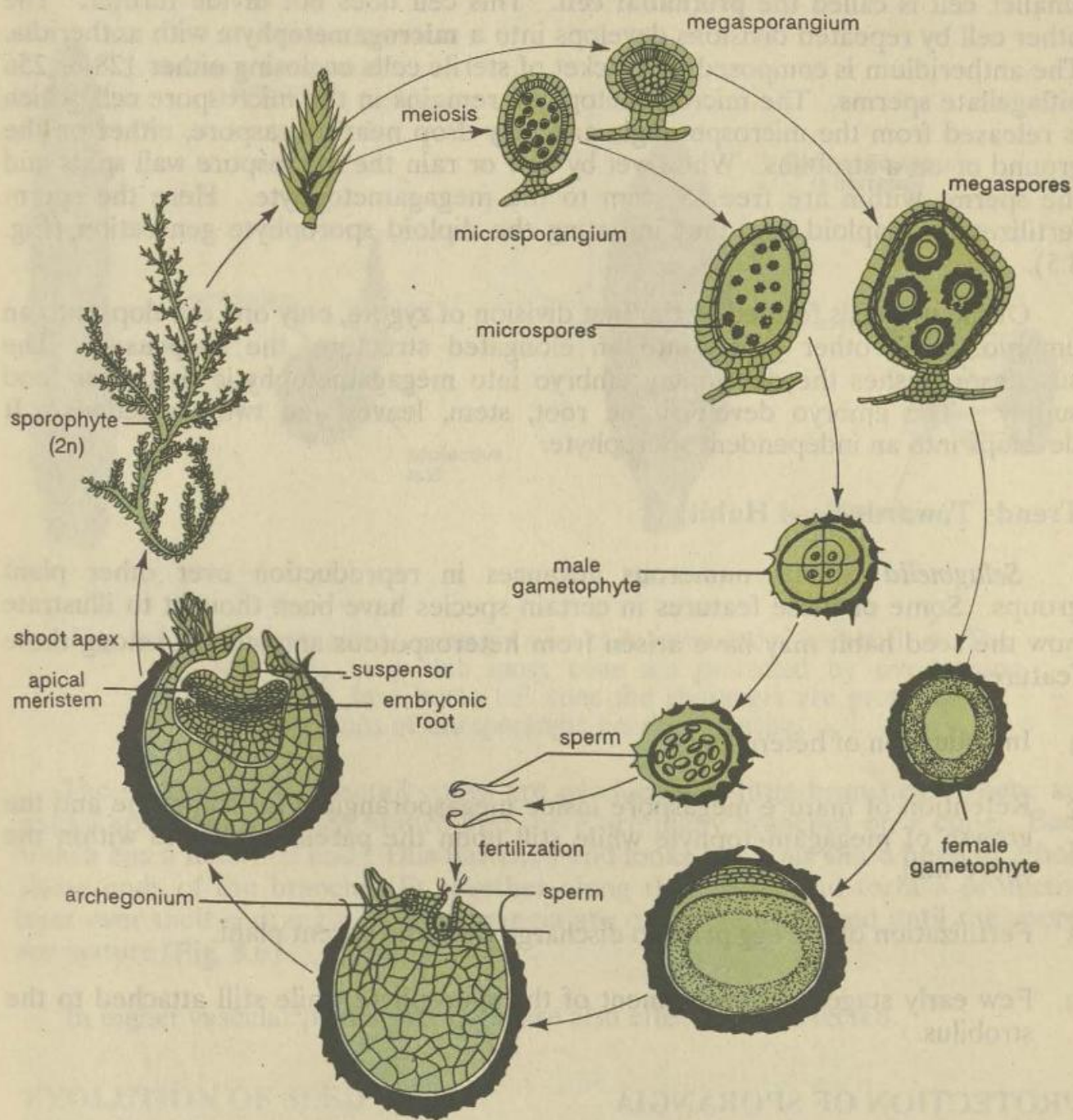


Fig. 8.5 The *Selaginella* life cycle. The sporophyte produces two kinds of spores (heterospory) following meiosis. Each gives rise to a morphologically distinct gametophyte. The megasporangium gives rise to a megagametophyte inside the megaspore, and following fertilization the young sporophyte is held there during early development.

stored in the megaspore is the major source of food for the female gametophyte and the developing embryo. The gametophyte increases in size, eventually rupturing the megaspore wall and the small colourless megagametophyte tissue protrudes. In the megagametophyte, female sex organs or archegonia are produced.

The haploid microspore also undergoes mitosis and forms two cells. The smaller cell is called the **prothallial cell**. This cell does not divide further. The other cell by repeated divisions develops into a **microgametophyte** with antheridia. The antheridium is composed of a jacket of sterile cells enclosing either 128 or 256 biflagellate sperms. The microgametophyte remains in the microspore cell, which is released from the microsporangia and may drop near megaspore, either on the ground or on a strobilus. When wet by dew or rain the microspore wall splits and the sperms within are free to swim to the megagametophyte. Here the sperm fertilizes the haploid egg, thus initiating the diploid sporophyte generation (Fig. 8.5).

Of the two cells formed by the first division of zygote, only one develops into an embryo. The other grows into an elongated structure, the **suspensor**. The suspensor pushes the developing embryo into megagametophytic tissue for food supply. The embryo develops the root, stem, leaves and two cotyledons. It develops into an independent sporophyte.

Trends Towards Seed Habit

Selaginella exhibits numerous advances in reproduction over other plant groups. Some of these features in certain species have been thought to illustrate how the seed habit may have arisen from heterosporous ancestors. Among these features are:

1. Introduction of heterospory.
2. Retention of mature megaspore inside megasporangium for sometime and the growth of megagametophyte while still upon the parent plant and within the spore wall.
3. Fertilization of the egg prior to discharge from the parent plant.
4. Few early stages of development of the sporophyte while still attached to the strobilus.

PROTECTION OF SPORANGIA

Primitive type of vascular plants had sporangia at the tips of upright branches. Here the sporangia are well placed for dispersal of their spores but are not protected in any way. Except in these few primitive vascular plants, the sporangia of green land plants are well protected. Let us see with the help of few examples, how this protection is provided. In many vascular plants sporangia are present in cones e.g. club mosses, horsetails and pines. In the case of club moss protection to sporangium is provided by a leaf. The sporangium is enveloped in a leaf. Many such leaves with sporangia form a cone (Fig. 8.6).

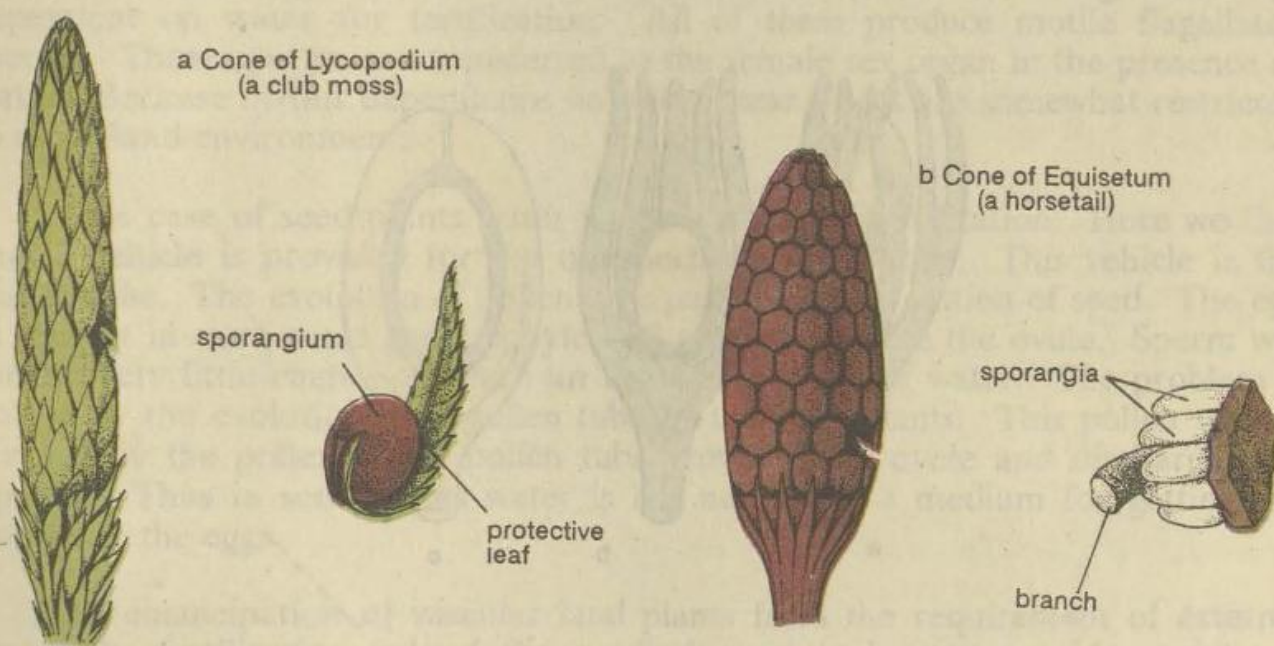


Fig. 8.6 The protected sporangia of a club moss and a horsetail. **a.** The sporangia in a club moss cone are protected by overlapping leaves. **b.** In a horse tail cone the sporangia are protected by flattened ends of the sporangia-bearing branches.

The sporangia of horsetail cones are produced on little branches. There are several sporangia on each branch and there are many branches on a cone. Each branch has a flattened end. This flattened end looks like a six sided head of a bolt. These ends of the branches fit together along their sides and form a protective layer over their sporangia. The sporangia are completely covered until the spores are mature (Fig. 8.6).

In higher vascular plants sporangia are also effectively protected.

EVOLUTION OF SEED

One of the most interesting problem in the evolution of the vascular plants is the evolution of seed. A seed may be considered as a megaspore producing sporangium which has a protective cover or integument around the embryo. The evolution of seed habit in vascular plants involved the following stages;

1. Development of Heterospory:

All seed plants are heterosporous. They produce two types of spores i.e. microspores and megaspores. The microspore grows into a male gametophyte and megaspore grows into a female gametophyte. The two kinds of spores are formed in two different kinds of sporangia, i.e. microsporangia and megasporangia.

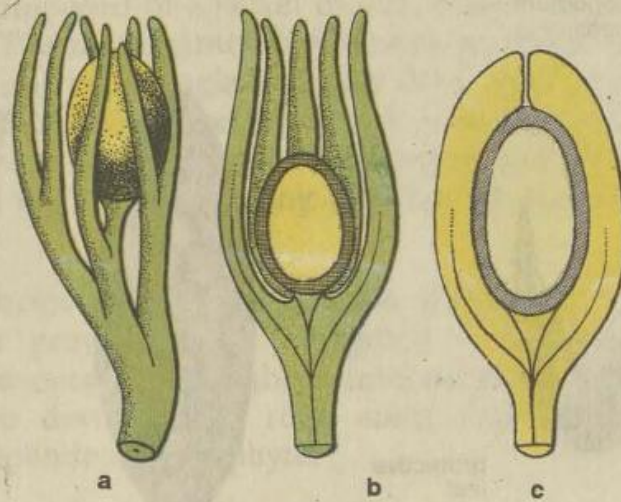


Fig. 8.7 Steps in seed evolution. Fossil evidence for step **b** suggests hypothetical step **a**. Step **c** shows an integumented seed of a modern plant.

2. Retention of the Megaspore inside the Sporangium:

Instead of being shed from the sporangium like the spores of all other green land plants, the megaspores of seed plants are permanently retained and protected inside the sporangium. Here the megaspore develops into a tiny female gametophyte.

3. Formation of an Integument around the Megasporangium and Evolution of Ovule:

If we look at the fossil record of Carboniferous period (282-350 million years ago), we find certain fern like plants that bore seed like structures. Each of their megasporangium was nearly surrounded by outgrowths from the sporophyte. These outgrowths appear to have been little branch like structures which during evolution have become fused as an envelop or an integument around the sporangium. The integumented megasporangium in which megaspore is retained is called an **ovule**. (Fig. 8.7).

In an immature seed (ovule) we find in addition to the protective covering of the integument, large quantities of food. Thus the ovule not only protects the female gametophyte from the environments, it also provides food for new offsprings. Clearly seed protection is one of the important characters that better adapts vascular plants to their environments and makes them the prominent form of vegetation on our earth.

4. Evolution of Pollen Tube

Non-vascular land plants and lower vascular plants including ferns are dependent on water for fertilization. All of them produce motile flagellated sperms. These sperms are transferred to the female sex organ in the presence of water. Because of this dependence on water these plants are somewhat restricted to moist land environments.

In the case of seed plants water is not needed for fertilization. Here we find that a vehicle is provided for the transportation of sperms. This vehicle is the **pollen tube**. The evolution of pollen tube parallels the evolution of seed. The egg is present in the female gametophyte well protected inside the ovule. Sperm will have a very little chance to reach an egg merely through water. The problem is solved by the evolution of a pollen tube by the seed plants. This pollen tube is formed by the pollen. The pollen tube grows to the ovule and discharges the sperms. Thus in seed plants water is not needed as a medium for getting the sperms to the eggs.

This emancipation of vascular land plants from the requirement of external water for fertilization helped the seed plants to adopt to a wide variety of environments. These environments range from the upland environments of the mountains to the arid conditions of deserts.

QUESTIONS

1. What do we mean by the most primitive vascular plants? Describe their structure and reproduction.
2. What is the difference between microphyllous and megaphyllous leaf? Describe the evolution of microphyllous leaf.
3. What is a club moss? Describe the life cycle of *Selaginella*.
4. Which features in the life cycle of *Selaginella* are considered to be advanced and illustrate how seed habit may have arisen in the vascular plants.
5. Explain how a megaphyllous leaf has evolved.
6. Describe various steps in the evolution of seed.
7. How pollen tube had played an important role in the success of seed plants?

LAND PLANTS

HIGHER VASCULAR PLANTS

9

As mentioned in last Chapter, higher vascular plants are seed producing plants. They are also sub groups of tracheophyta. Higher vascular plants have two main subdivisions, gymnosperms and angiosperms.

Gymnosperms

The name gymnosperm means naked seeded plants. (Gymno-naked and sperm-seed). These plants generally have cones rather than flowers and their seeds are not enclosed in fruits. They produce seeds on the surface of scales. In hilly areas of Pakistan we have luxuriant forests of conifers. Some of the conifers found in our northern areas include *Pinus* (pines, chilgoza, chir or kail), *Abies* (firs) and *Cedrus* (cedars). They are tall evergreen trees.

Angiosperms

These are the flowering plants which have seed enclosed in a fruit. They are found in all land habitat. They are about 230 thousand species. Some of the important angiosperms are rose, mustard, shisham, rice, wheat and maize etc.

PINUS - An Example of Gymnosperms

Life History of *Pinus*

Pinus, a conifer belongs to the group gymnosperms. *Pinus* tree is sporophyte. It is differentiated into root, stem and leaves. There are two types of leaves, needle shaped green leaves and scale leaves. The tree produces reproductive structures called **cones**. Cones are of two kinds, male and female cones. Male cones are smaller while female cones are larger. Both cones are produced on the same tree (Fig. 9.1).

Both male and female cones consist of closely and spirally arranged sporophylls (sporangia bearing leaves). Each sporophyll of a male cone (microsporophyll) has two microsporangia or pollen sacs on its under surface. In each pollen sac a large number of pollens or microspores are produced by meiosis. Each pollen grain has two large air sacs which help in wind dispersal. The pollens are released from the pollen sacs in large numbers. They are taken by wind to the female cone.

Each sporophyll of female cone (megasporeophyll) consists of a lower bract scale and an upper ovuliferous scale. On the upper surface of the ovuliferous scale two ovules are present side by side. Inside each of these ovules four megaspores are produced by meiosis. Normally one megaspore remains functional.

The microspore forms a reduced **male gametophyte**. A pollen tube is formed by the pollen grain. In this pollen tube two sperms are produced (Fig. 9.1).

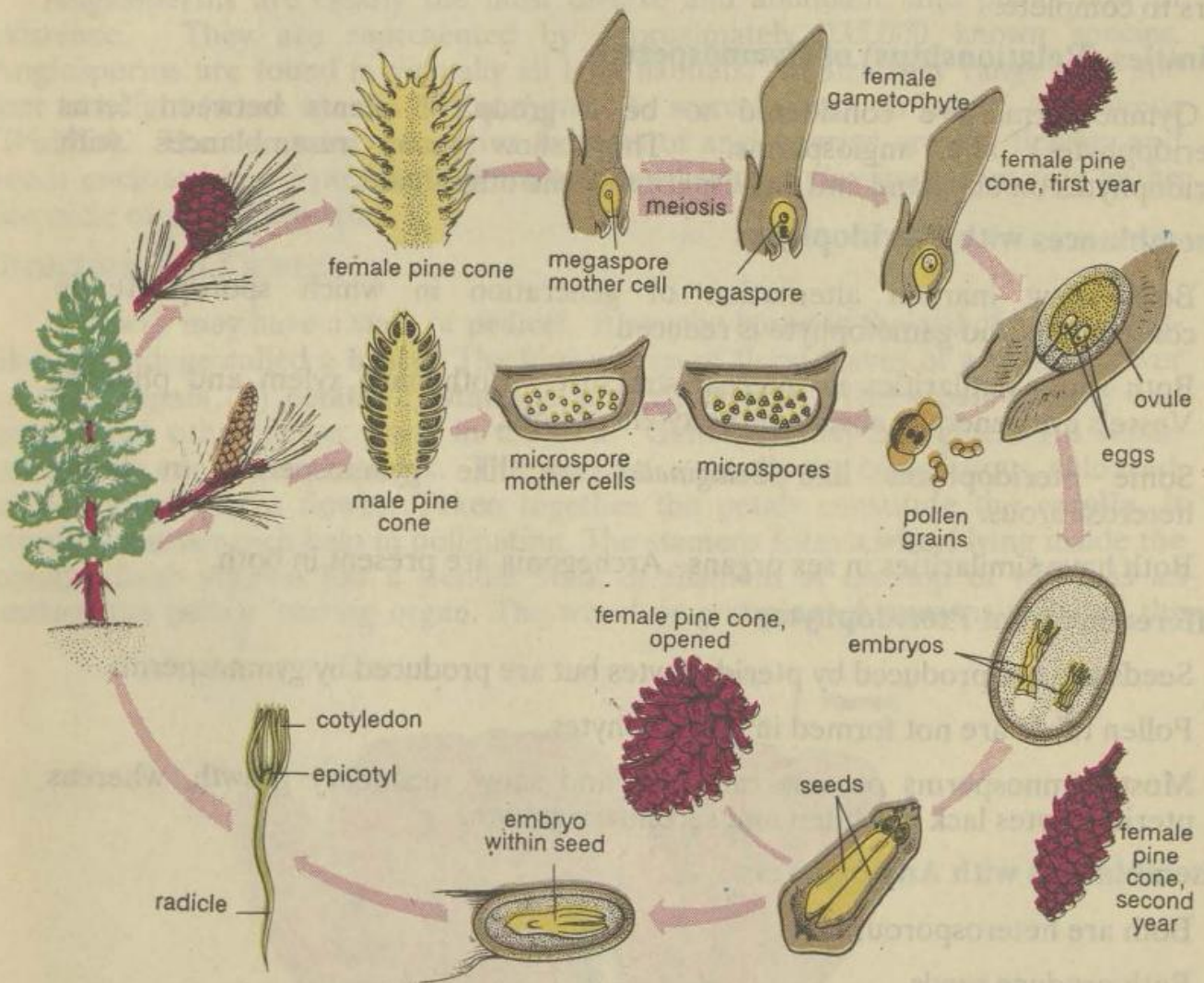


Fig. 9.1 Life cycle of pine. The mature sporophyte (pine tree) has female pine cones that produce megaspores that develop into female gametophyte generations and male pine cones that produce microspores that develop into male gametophyte generations (mature pollen grains). Following fertilization, immature sporophyte generations are present in seeds located on the female cones.

The functional megaspore divides repeatedly by mitosis and forms a **female gametophyte**. When matures the female gametophyte produces two to five tiny archegonia. Egg cell develops in the archegonium. In *Pinus* and other seed plants megaspore is never released from the sporangium and the female gametophyte derived from it remains embedded in the sporangium. This sporangium is still

attached to the female cone scale. The composite structure consisting of integument, sporangium and female gametophyte is called an **ovule**. The scales of female cone secrete a sticky substance that captures wind borne pollen. Pollen grains form a pollen tube which grows through the sporophyte and ovule tissue to transport a sperm to the egg. Following fertilization, the zygote grows and develops into a pine embryo. The ovule thus develops into a seed. The seed germinates and forms a new sporophyte of *Pinus*. The process described above takes about three years to complete.

Affinities (Relationships) of Gymnosperms

Gymnosperms are considered to be a group of plants between ferns (pteridophytes) and angiosperms. They show many resemblances with pteridophytes on one hand and angiosperms on the other hand.

Resemblances with Pteridophytes

1. Both^o show marked alternation of generation in which sporophyte is conspicuous and gametophyte is reduced.
2. Both show similarities in internal structure. Both have xylem and phloem. Vessels are generally absent in the xylem of both.
3. Some pteridophytes like *Selaginella* are like gymnosperms in being heterosporous.
4. Both have similarities in sex organs. Archegonia are present in both.

Differences from Pteridophytes

1. Seeds are not produced by pteridophytes but are produced by gymnosperms.
2. Pollen tubes are not formed in pteridophytes.
3. Most gymnosperms possess cambium and show secondary growth, whereas pteridophytes lack cambium and secondary growth.

Resemblances with Angiosperms

1. Both are heterosporous.
2. Both produce seeds.
3. Both produce pollen tubes.
4. Both have similarities in internal structure. Internal anatomy in general, resembles that of a dicot stem.

Differences from Angiosperms

1. Ovules are naked in gymnosperms but are enclosed within the ovary in angiosperms.
2. In angiosperms vessels are present in the xylem. In most gymnosperms they are absent.

3. Double fertilization is absent in gymnosperms but is present in angiosperms. The endosperm formed in angiosperm is triploid ($3n$) whereas in gymnosperms it is monoploid ($1n$).
4. Angiosperms lack archegonia but gymnosperms have archegonia.

ANGIOSPERMS (FLOWERING PLANTS)

Angiosperms are clearly the most diverse and abundant land plants now in existence. They are represented by approximately 235,000 known species. Angiosperms are found in virtually all land habitats. In size they range over 300 feet in height (some species of *Eucalyptus*) to scarcely 1mm. in length, duckweeds (*Wolffia*). The two most distinctive features of angiosperms are the flowers and seeds enclosed in a fruit. Both these unique structures play important role in the life cycle of an angiosperm.

Structure of a Flower

A flower may have a stalk or **pedicel**. It may be borne in the axil of a small leaf-like appendage called a **bract**. The four whorls of floral leaves of a typical flower are: (a) **sepals**, (b) **petals**, (c) **stamens** and (d) **carpels**. The sepals enclose and protect the other flower parts in the bud. Generally they are green. All sepals collectively constitute the **calyx**. The petals are usually the conspicuous, coloured, attractive part of a flower. Taken together the petals constitute the **corolla**. It attracts insects which help in pollination. The stamens form a **whorl** lying inside the corolla. Each stamen has a slender stalk or filament at the top of which is an **anther**, the pollen bearing organ. The whorl or grouping of stamens is called the

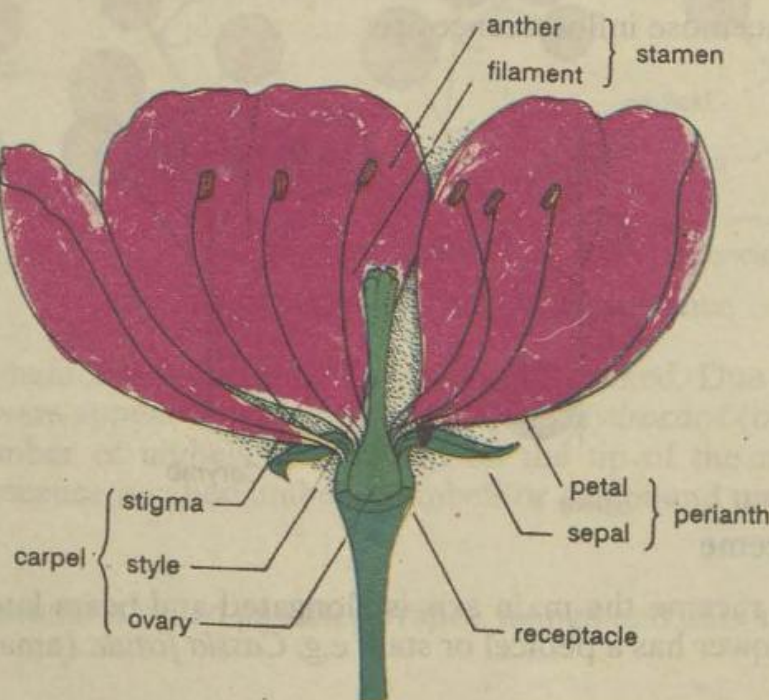


Fig 9.2 Anatomy of a typical dicot flower. The stamen consists of the anther and filament. The carpel consists of the ovary, style, and stigma. Several fused carpels constitute a pistil.

androecium. It is the male gamete producing part of the flower. The pistil or carpels form the central whorl. Collectively they are spoken off as a **gynaecium**. It is the female gamete producing part of a flower. There are generally three distinct parts of each carpel: a, an expanded basal portion, the **ovary** in which ovules are born, b; the **style** and c, the **stigma** which forms the top. The pollen is deposited on the stigma (Fig. 9.2).

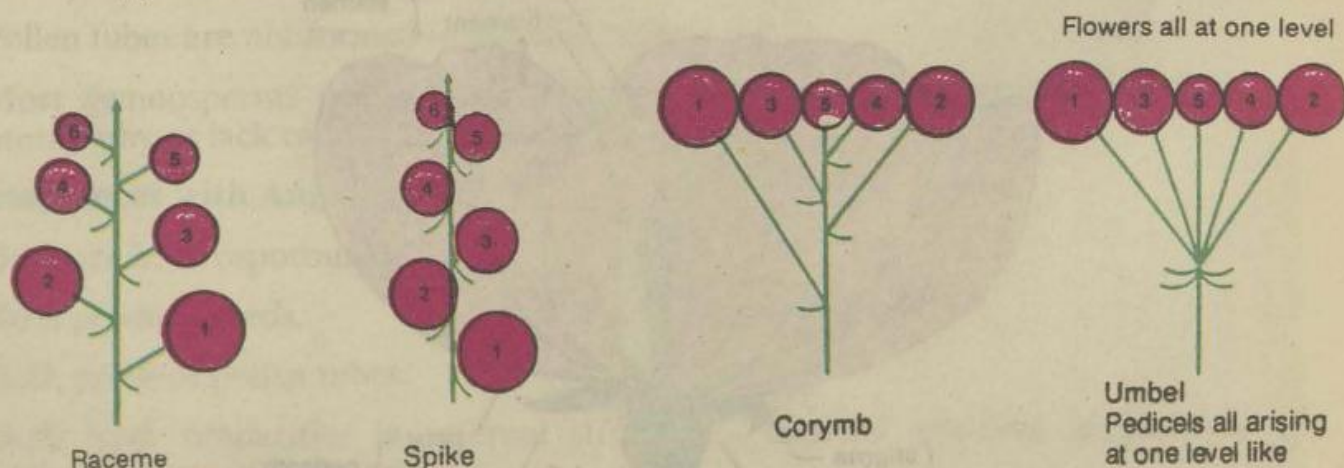
The term **perianth** is applied to the calyx and corolla collectively. It is frequently used to describe flowers in which calyx and corolla are not distinguishable.

Inflorescence

In some angiosperms individual flowers are quite large and are borne singly on the pedicel. Such flowers are termed **solitary flowers**. In most angiosperms the flowers are small and occur in groups. Such cluster of flowers arranged on the floral axis is called an **inflorescence**. Cluster of flowers in some way ensures pollination, fertilization and thus the reproductive success of the species.

The inflorescence may be racemose or cymose. In a **racemose** inflorescence the main axis continue to grow indefinitely until the last flower is formed at its apex. The oldest flowers are toward the base of the inflorescence and the youngest ones toward the apex. In a **Cymose** inflorescence the main axis soon ends in a flower. One, two or more lateral branches develop below the terminal flower, each ending in a flower like the main axis. In this case the terminal flower is the oldest and the lateral flowers are younger. (Fig. 9.3).

Chief type of racemose inflorescence are:



1. Typical Raceme

In a typical raceme the main axis is elongated and bears laterally a number of flowers. Each flower has a pedicel or stalk e.g. *Cassia fistula* (amaltas).

2. The Spike

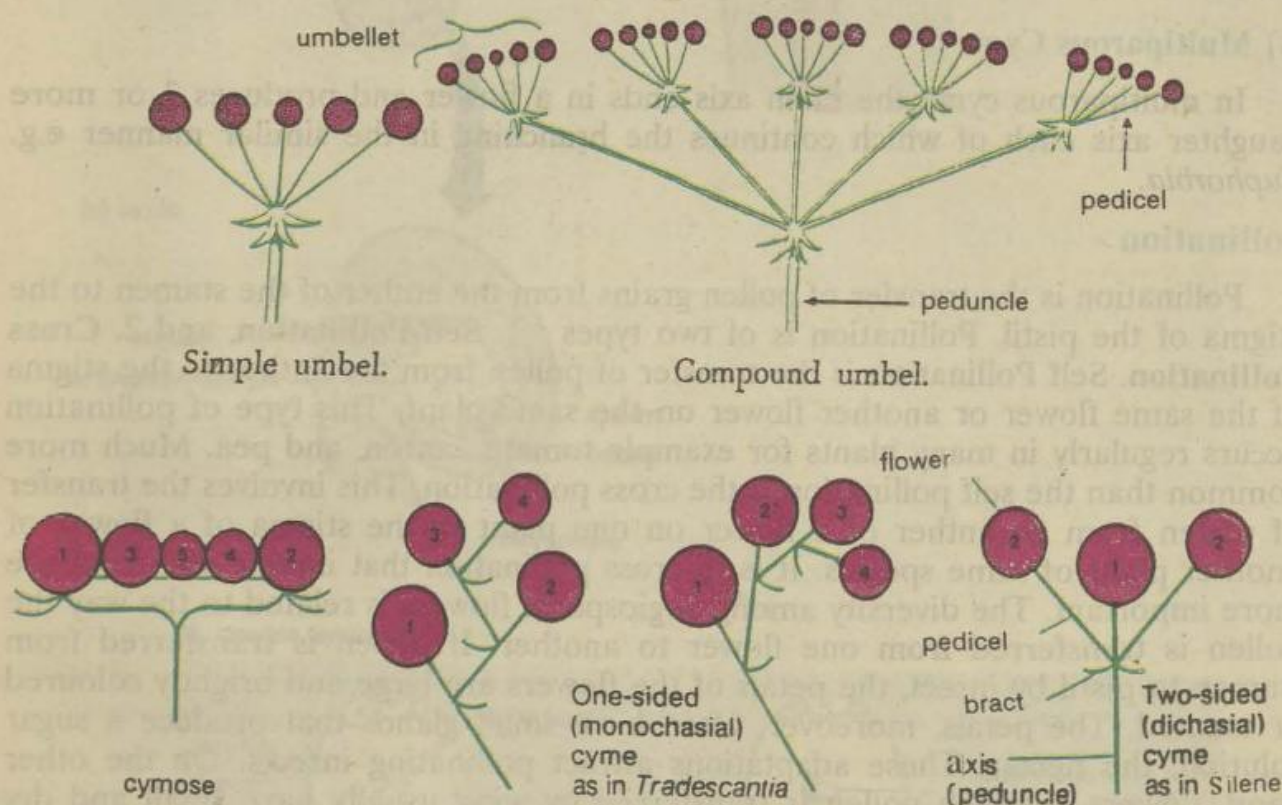
The spike is a racemose inflorescence in which the main axis is elongated like raceme but the flowers are sessile i.e. without stalk e.g. *Achyranthus* (puth kanda) and bottle brush.

3. Catkin

It is a spike that usually bears only pistillate or staminate flowers. Examples are mulberry and willow.

4. Corymb

In this case the main axis is comparatively short and the stalks of the lower flowers are longer than those of the upper younger ones. As a result, all the flowers lie at about the same level e.g. *Iberis* (candytuft)



5. Umbel

Fig. 9.3 Common types of inflorescence.

In umbel the main axis is shortened. Flowers are stalked. Due to shortening of main axis, the flowers appear to arise at one level e.g. *Hydrocotyl* (brahmi booti). In some cases a number of umbels are present on the tip of the main axis such a compound inflorescence is called umbel of umbels or **compound umbel** e.g. carrot.

6. Panicle

A branched raceme is called **panicle**. Grapes, mango and oats are examples.

7. Capitulum

In capitulum or head, the flowers are sessile and are crowded together on a very short axis. It looks like a single flower e.g., sunflower.

Chief types of cymose inflorescence are:

i) Uniparous Cyme (Monochasial Cyme)

In this case the main axis ends in a flower below which it produces one daughter axis only. The daughter axis as well as each succeeding one again ends in flower and gives rise to one daughter axis only e.g. *Begonia*, *Tradescantia*.

ii) Biparous Cyme (Dichasial Cyme)

In biparous cyme the main axis ends in a flower and produces two daughter axis. Each of the two daughter axis again ends in a flower and produces two daughter axis which may continue the branching in the same manner e.g. *Silene*, *Ipomoea*

iii) Multiparous Cyme

In multiparous cyme the main axis ends in a flower and produces 3 or more daughter axis each of which continues the branching in the similar manner e.g. *Euphorbia*.

Pollination

Pollination is the transfer of pollen grains from the anther of the stamen to the stigma of the pistil. Pollination is of two types : 1. **Self-Pollination**, and 2. **Cross Pollination**. Self Pollination is the transfer of pollen from the anther to the stigma of the same flower or another flower on the same plant. This type of pollination occurs regularly in many plants for example tomato, cotton, and pea. Much more common than the self pollination is the cross pollination. This involves the transfer of pollen from an anther of a flower on one plant to the stigma of a flower of another plant of same species. It is in cross pollination that insects and wind are more important. The diversity among angiosperm flowers is related to the way the pollen is transferred from one flower to another. If pollen is transferred from stamen to pistil by insect, the petals of the flowers are large and brightly coloured or scented. The petals, moreover, often have small glands that produce a sugar solution, the nectar. These adaptations attract pollinating insects. On the other hand, flowers in which pollen is transferred by wind usually have small and dry sepals and petals or none at all. They are often located high up on the plant and produce an abundance of pollens. Their pistils commonly have large, long or feathery structures at the tips as in grasses. These structures are covered with a sticky fluid. These adaptations increase the likelihood of wind pollination.

Cross pollination brings about a more diverse combinations of hereditary units (genes) of the two parents. This results in increased variability of the offspring and greater adaptability to new environmental conditions of evolutionary advantage to the species.

Life Cycle of an Angiosperm

Angiosperms like other vascular plants exhibit an alternation of generations. The mature plant with root, stem and leaves represent the sporophyte. The male

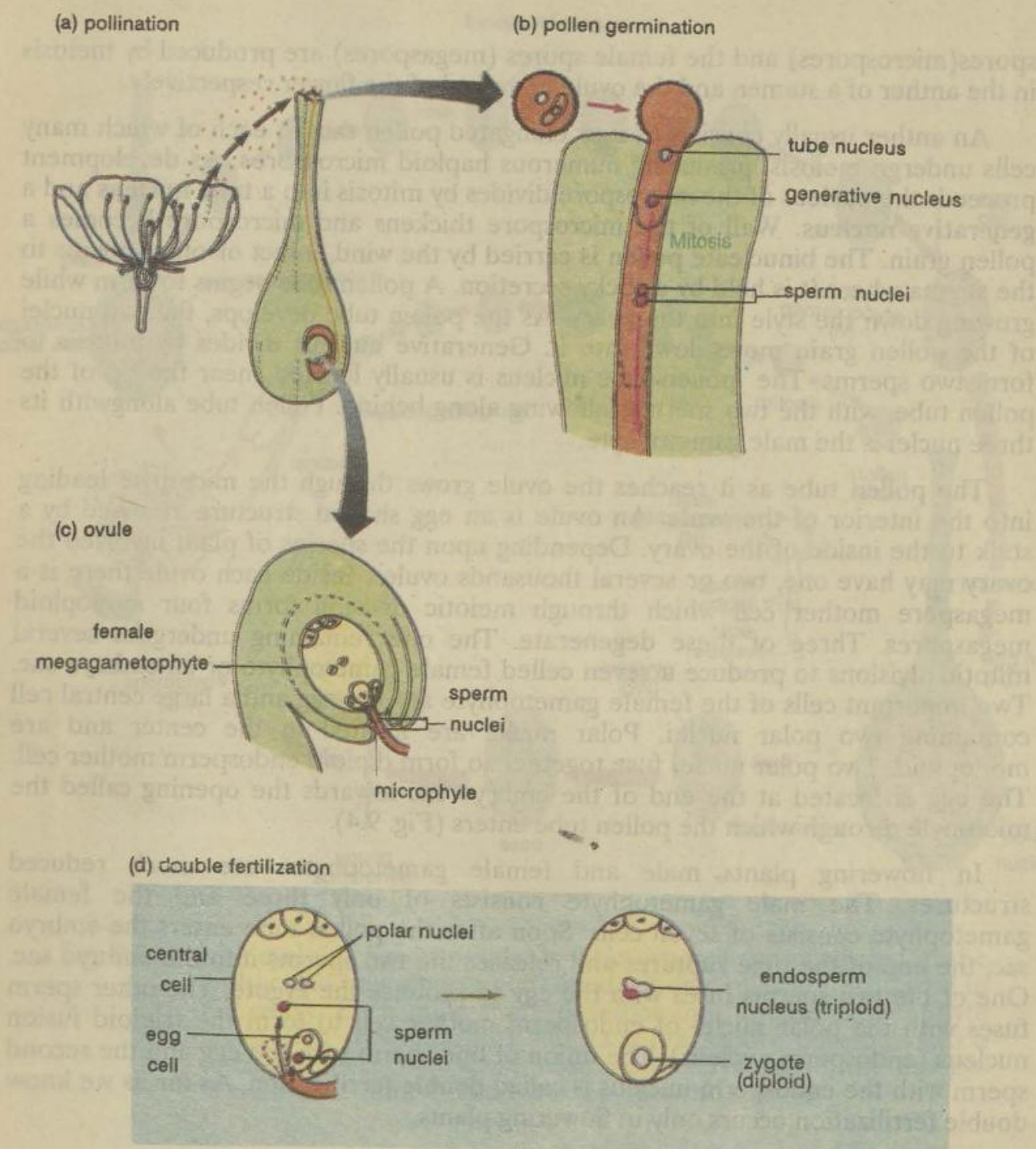


Fig 9.4 Pollination, pollen germination, pollen tube growth, and double fertilization. (a) Pollination occurs when pollen lands on a stigma. (b) As the pollen germinates, the generative cell undergoes mitosis to form two haploid sperm cells that pass down the elongating pollen tube. (c) When the pollen tube enters the micropyle of a mature ovule, (d) a double fertilization takes place. One sperm cell fuses with the egg cell, forming the zygote. The other fuses with the central cell containing the polar nuclei to form the triploid endosperm nucleus. This endosperm nucleus divides to produce many triploid endosperm nuclei; as that occurs, the zygote divides and begins to form the embryo.

spores(microspores) and the female spores (megaspores) are produced by meiosis in the anther of a stamen and the ovule of a pistil of the flower respectively.

An anther usually consists of four elongated pollen sacs in each of which many cells undergo meiosis, producing numerous haploid microspores. As development proceeds the nucleus of the microspore divides by mitosis into a **tube nucleus** and a **generative nucleus**. Wall of the microspore thickens and microspore becomes a pollen grain. The binucleate pollen is carried by the wind, insect or other means to the stigma where it is held by a sticky secretion. A pollen tube begins to form while growing down the style into the ovary. As the pollen tube develops, the two nuclei of the pollen grain move down into it. Generative nucleus divides by mitosis to form two sperms. The pollen tube nucleus is usually located near the tip of the pollen tube, with the two sperms following along behind. Pollen tube along with its three nuclei is the male gametophyte.

The pollen tube as it reaches the ovule grows through the micropyle leading into the interior of the **ovule**. An ovule is an egg shaped structure attached by a stalk to the inside of the ovary. Depending upon the species of plant involved the ovary may have one, two or several thousands ovules. Inside each ovule there is a megaspore mother cell which through meiotic division forms four monoploid megaspores. Three of these degenerate. The one remaining undergoes several mitotic divisions to produce a seven celled female gametophyte or an **embryo sac**. Two important cells of the female gametophyte are the egg and a large central cell containing two polar nuclei. Polar nuclei are located in the center and are monoploid. Two polar nuclei fuse together to form diploid endosperm mother cell. The egg is located at the end of the embryo sac towards the opening called the micropyle through which the pollen tube enters (Fig. 9.4).

In flowering plants, male and female gametophytes are much reduced structures. The male gametophyte consists of only three and the female gametophyte consists of seven cells. Soon after the pollen tube enters the embryo sac, the end of the tube ruptures and releases the two sperms into the embryo sac. One of the two sperms fuses with the egg to produce the zygote. The other sperm fuses with the polar nuclei of endosperm mother cell to form the triploid fusion nucleus (endosperm nucleus). The union of one sperm with the egg and the second sperm with the endosperm nucleus is called **double fertilization**. As far as we know double fertilization occurs only in flowering plants.

Seed and Fruit Formation.

The zygote will develop into an embryonic plant while the endosperm nucleus develops into **endosperm tissue** within the ovule (Fig. 9.5). Endosperm tissue is triploid. The endosperm contains large quantities of starch. The starch serves as reserve food material and is broken down to glucose when the seed germinates. After double fertilization the ovule increases rapidly in size as a result of the formation of endosperm tissue and the development of the new embryo. The embryo consists of one or more cotyledons, an epicotyl and a hypocotyl. Both the epicotyl and the hypocotyl are parts of a rod like axis attached to the cotyledons. The cotyledons digest and absorb the endosperm and make its stored food available

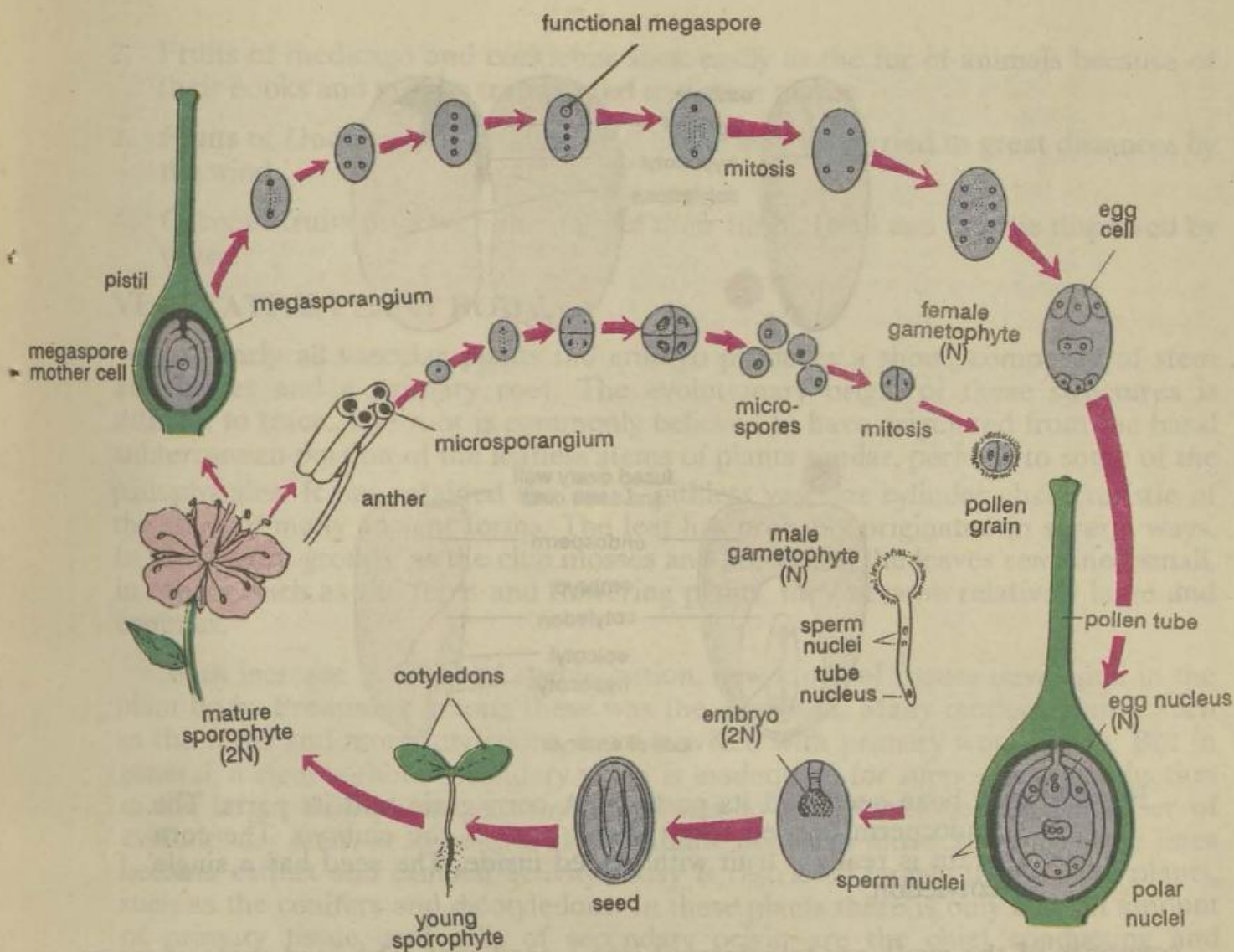


Fig. 9.5 Life cycle of flowering plants. Microspores are produced in the anther and megaspores contained within ovules are produced in the ovary. Each microspore develops into a male gametophyte generation (pollen grain) and each megaspore develops into a female gametophyte generation. After fertilization, the embryo is enclosed within a seed that disperses the species.

for the growth of the epicotyl and the hypocotyl. The cotyledons of some flowering plants, bean for example digest, absorb and store the food from the endosperm as the ovule is maturing into seed. Their cotyledons, therefore, become greatly enlarged.

In many other flowering plants, such as corn or castor-oil, the endosperm tissue continues to grow as the ovule matures into a seed. Thus in a corn grain most of the seed is endosperm and the embryo is located on one side (Fig. 9.6).

As an ovule matures into a seed, there are other changes in addition to the formation of an embryo and the accumulation of stored food. The protective

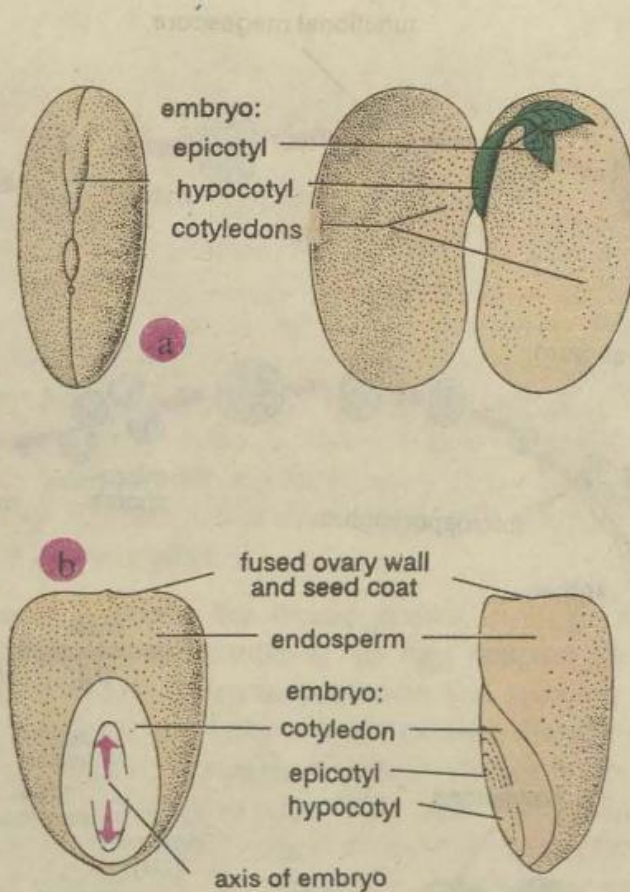


Fig. 9.6 a A bean seed and its parts. b. A corn grain and its parts. The endosperm (stored food) is not part of the embryo. The corn grain is really a fruit with a seed inside. The seed has a single cotyledon.

coverings of the ovule are transformed into a seed coat. The seed coats of many seed plants are tough and they protect the enclosed embryonic plant from injury.

While the seed coat develops, other activities are taking place. Most of the flower parts begin to die but the ovary enlarges rapidly. This enlarged ovary is called a **fruit**. There is lot of diversity in fruits. Fruits may be dry or fleshy. Nuts and grains are examples of dry fruits. Mangoes, oranges, melons and tomatoes are examples of fleshy fruits. Some fruits are formed without fertilization and therefore lack seeds. Such fruits are called **parthenocarpic fruits**. Banana is an example of such fruits.

Dispersal of Fruit and Seed.

In addition to protecting the seed a fruit has another important function. It aids in seed dispersal. If the seeds are to germinate they must land where there is a suitable environment. There are different ways by which seeds and fruits are dispersed.

1. Because of good taste many fruits, e.g. grapes, guavas, mulberries, are eaten by animals. The seeds of these fruits pass undigested through the digestive systems of the animals and are usually deposited at a distance from the parent plant.

2. Fruits of medicago and cocklebur stick easily to the fur of animals because of their hooks and may be transported to distant places.
3. Fruits of Dodonaea are winged and hence may be carried to great distances by the wind.
4. Coconut fruits float with the help of their fibrous wall and may be dispersed by water.

VEGETATIVE PLANT BODY.

In nearly all vascular plants the embryo produces a shoot, composed of stem and leaves and a primary root. The evolutionary origin of these structures is difficult to trace. The root is commonly believed to have originated from the basal subterranean portion of the leafless stems of plants similar, perhaps to some of the psilophytales. It has retained the solid, pithless vascular cylinder characteristic of the stem of many ancient forms. The leaf has probably originated in several ways. In some plant groups, as the club mosses and horsetails, the leaves remained small, in others, such as the ferns and flowering plants, they became relatively large and complex.

With increase in size and specialization, new kinds of tissues developed in the plant body. Prominent among these was the **cambium**. Many modern plants, such as the ferns and monocotyledons, have survived with primary wood alone. But in general, a stem without secondary wood is inadequate for support and conduction in the larger land plants. A cambium seems to have developed in a number of evolutionary lines, in some as early as **middle devonian** times. Many of these lines became extinct and cambial activity today is restricted largely to the seed plants, such as the conifers and dicotyledons. In these plants there is only a small amount of primary tissue, and cells of secondary origin are the chief conducting and supporting tissues of the plant.

It is difficult to visualize what a modern landscape would look like if a cambium had not evolved. Without this tissue there would be no timber trees. The absence of tree life would greatly have affected the development of civilization, for man has been dependent upon the products of the forest from the beginning of the history.

STORAGE OF FOOD AND WATER.

On the basis of the nature of the habitat to which plants adapted, they may be classified as mesophytes, xerophytes and hydrophytes. **Mesophytes** grow in an environment that is neither very wet nor very dry. **Xerophytes** are adapted to survival under conditions of a limited supply of water in its habitat, while **hydrophytes** grow in or near water, partly or entirely submerged. Both xerophytes and hydrophytes are thought to have originated from mesophytes and by evolutionary change have become adapted to new environments.

The xerophytes include species from many families in no way closely related phylogenetically, but resemble each other more or less closely in vegetative structure. A class of xerophytes, the **succulents** have developed in a manner by which they can store large amount of food and water.

Among the plant families containing succulents are the cactus, spurge, milkweed, stone crop, lily and amaryllis. The chief characteristic of the succulent type is that the bulk of the plant body is composed of water storage cells that maintain the plant during the period of drought. The succulent organs are generally the stems or leaves, in some cases the roots. If the leaves are succulent, the stem is generally much reduced; if the succulent organ is the stem, the leaves are reduced and absent. The volume of the shoot is great in proportion to the surface exposed and this, combined with well developed cuticle and other features, retards the rate of water loss so that the transpiration rate is low.

Many plants produce underground stem and are significant as regions of food storage. Some are utilized by man as important source of food. Underground stems are of several kinds, each specialised in different ways (Fig. 9.7).

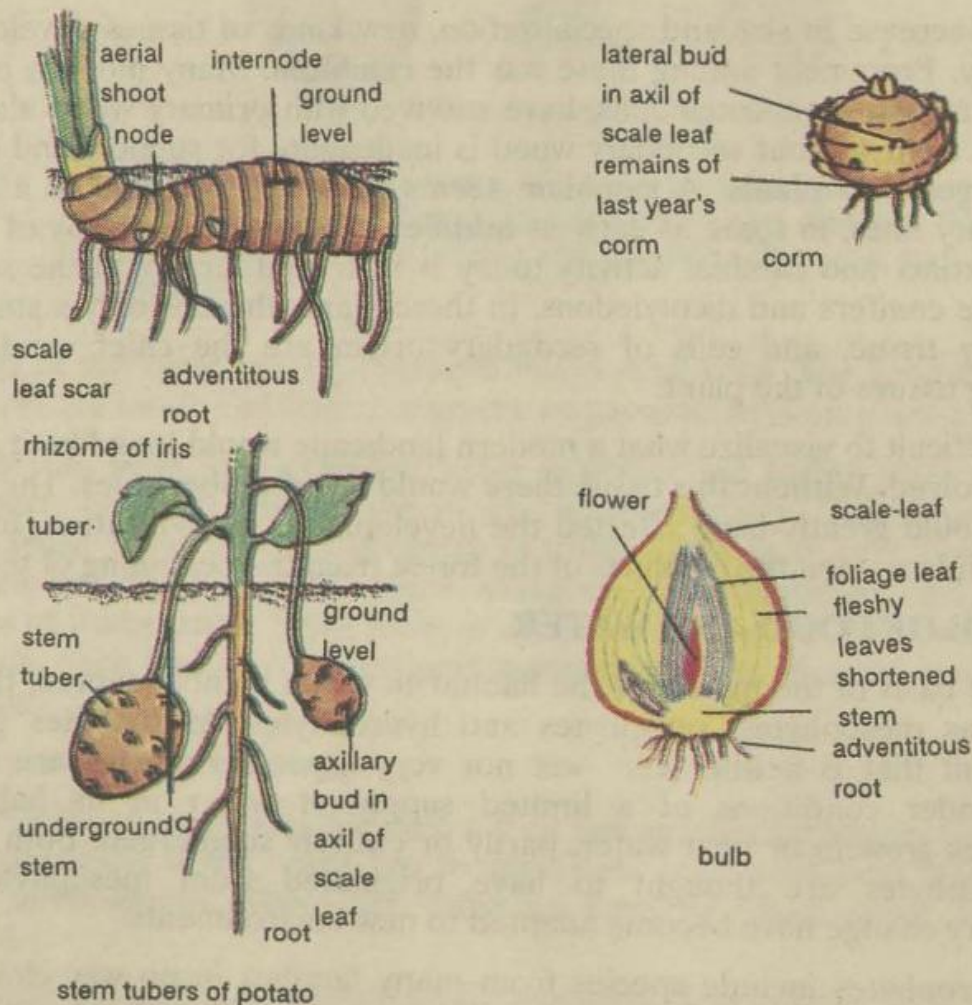


Fig. 9.7 Different kinds of underground stems

- (a) **Rhizomes:** Rhizomes are perennial stem usually horizontal in position. Rhizomes are rich in accumulated food, commonly in the form of starch. Rhizomes are especially characteristic of herbaceous perennials e.g. iris.
- (b) **Tuber:** A tuber is a much enlarged and swollen portion of an underground branch of the vertical axis. The most familiar example is the potato tuber. The food value of potato tubers for humans results from the enormous number of starch grains that are stored in the cortical and pith cells. Almost the entire mass of tuber is storage parenchyma. The "eyes" are actually buds at nodes, and the bulky appearance results from the compressed, unexpanded internodes. As long as the piece of tuber contains at least one "eye" when it is planted, shoots and roots will develop and a new plant results.
- (c) **Corm:** A corm is an underground stem that is short, thickened and fleshy and contains stored foods. Examples of corms are found in gladiolus, crocus, colocasia (kachalo) and tuberous begonias. The corms of family Araceae (arvi, kachalo) are extensively used for food.
- (d) **Bulb:** A bulb is a very short stem wrapped in thickened, fleshy bulb scales, which are modified leaves. The scales are the chief sites of food accumulation. Examples are onions and hyacinth. In onion, the fleshy leaves contain large amounts of sugars but no starch. The odour and tear producing characteristics of onions are caused by aromatic oils.

UPLAND MIGRATION

When we study the evolution of land plants, we find that these plants are well adapted for life on land. Some of the features which make them better adapted for life on land are:

1. Presence of vascular tissue i.e., xylem and phloem provides support and is used for the conduction of water and food.
2. True roots are present in vascular plants and help in better absorption of water.
3. The plant is protected from drying by an epidermis with a waterproof layer called cuticle.
4. Stomata or pores are present on the leaf for exchange of gases.
5. Fertilization in gymnosperms and angiosperms is not dependent on water. Male gametes of these plants are transferred by pollen tubes.
6. The seed is a structure found only in gymnosperms and angiosperms. This structure with reserve food material is well suited for life on land.

With the evolution of all these features, the land plants were no longer dependent on water for their reproduction. They now migrated to almost all available habitats. Some of them migrated upland and formed successful vegetation in these areas.

CLASSIFICATION OF PLANTS

Plants, like animals, show much variation in size, shape and colour. There are nearly 550,000 known species of plants. For a logical and meaningful study, these plants are arranged into groups and sub-groups. The arrangements of plants into groups and sub-groups is called plant classification. The branch of biology which deals with classification is called **Taxonomy**.

Basis for Classifications

The major basis of classification is homologous structures. Taxonomists examine the structures of organisms when studying them in order to determine the similarities. According to the theory of evolution, **homologous** structures indicate a common ancestry. Therefore, they are valuable clues to biologist attempting to classify organisms.

Comparative biochemistry, genetics and cytology can solve many problems in classification.

Units of Classification

In classification of plants various units are used. **Species** represents the lowest category of taxonomic grouping. A species is a group of individuals that can breed with one another in nature and produce fertile offsprings. Members of a species resemble one another fairly closely. Species with many similar characteristics are grouped into the same **genus** (plural genera). Similar genera are grouped together in a **family**. Closely related families are grouped in **order**. A group of similar orders make up a **class**. Related classes comprise a **phylum** (plural phyla). Finally the phyla are grouped together in a **kingdom**. The name of the plant phyla usually ends in *phyta*; the ending *-eae* indicates class; the ending *-ales* is used for orders; and the ending *-aceae* indicates family.

Naming the Plant: Binomial Nomenclature

- Carolus Linnaeus in 1753 established the rules that are used for naming organism. Linnaeus gave every species that he knew a name of two words. Hence his system is known as binomial nomenclature. The name of species are derived from Latin or Greek. The first word of the species name is the name of genus to which it belongs. The second name is the species name. Thus shisham tree is given the name *Dalbergia sissoo*. Here *Dalbergia* is the name of the genus and *sissoo* is the name of the species. First letter of a genus is always capitalized and both names of a species are underlined or italicized.

Using biological names is necessary for scientific exactness because of several reasons. First, there is no other single set of names available for all organisms. Second different languages have different names for the same organism. For example, the same plant is known as "gajor" in Urdu, "carrot" in English, mohrrube in German and zanahoria in Spanish. Whereas it is known by its biological name *Daucus carota* throughout the world. Third, same word may refer to different organisms.

Biological classification of Corn, *Zea mays*

Kingdom	Plantae
Phylum	Tracheophyta
Sub-phylum.....	Pteropsida
Class.....	Angiospermae
Order	Poales
Family.....	Poaceae
Genus	<i>Zea</i>
Species.....	<i>mays</i>

KINGDOMS IN THE LIVING WORLD

For many years biologists put all organisms into two kingdoms, Plants and Animals. One-celled organisms were put in one kingdom or the other depending on whether they were more like plants or more like animals. But, many one-celled organisms did not fit neatly into either group. For example *Euglena* has features of both kingdoms.

Some biologists still use the two kingdom system but many favour a third kingdom Protista to include all the single celled organisms that are intermediate between plants and animals (e.g., *Euglena*).

Other biologists have suggested establishing a fourth kingdom Monera to include the bacteria and blue green algae. Bacteria and blue green algae have many characteristics in common, such as the absence of a nuclear membrane. Bacteria and blue green algae are termed **prokaryotes**. All other living things are called **eukaryotes**.

Robert Whittaker in 1969 has assigned organisms to five kingdoms. He distinguished the Fungi as a kingdom separate from the others. Whittaker felt that fungi should be separated from plants because the fungi and green plants differ in cell wall composition, body plan, nutrition and reproduction. According to Whittaker there are five kingdoms:

1. Kingdom Monera:

Organisms in this kingdom are made of prokaryotic cells. Most species are one celled. They make their own food or obtain it from an outside source.

2. Kingdom Protista:

Organisms in this kingdom are made of eukaryotic cells. Many species are one celled. Some are colonial or even filamentous. They make their own food or take it from an outside source.

3. Kingdom Plantae:

Members of the plant kingdom are made of eukaryotic cells. Plants are

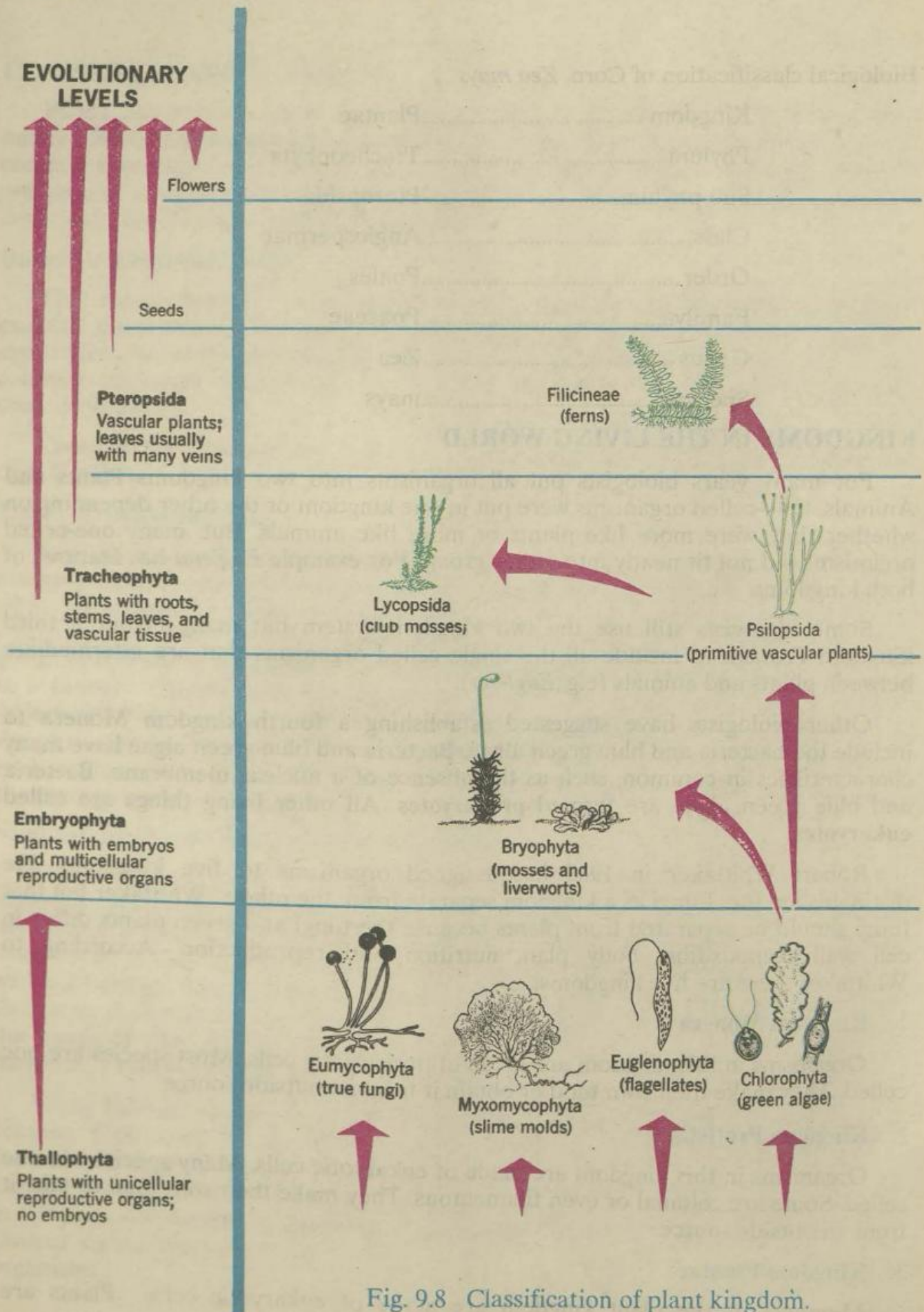


Fig. 9.8 Classification of plant kingdom.



Angiospermae
(flowering plants)



Gymnospermae
(conifers, cycads, ginkgos)



Sphenopsida
(horsetails)



PLANT KINGDOM

SUBKINGDOM—Thallophyta

Phylum	— Myxomycophyta
Phylum	— Eumycophyta
Phylum	— Cyanophyta
Phylum	— Rhodophyta
Phylum	— Chrysophyta
Phylum	— Phaeophyta
Phylum	— Euglenophyta
Phylum	— Chlorophyta

SUBKINGDOM—Embryophyta

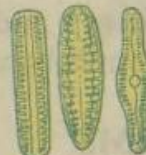
Phylum	— Bryophyta
Phylum	— Tracheophyta
Subphylum	— Psilopsida
Subphylum	— Lycopsidea
Subphylum	— Sphenopsida
Subphylum	— Pteropsida
Class	— Filicineae
Class	— Gymnospermae
Class	— Angiospermae



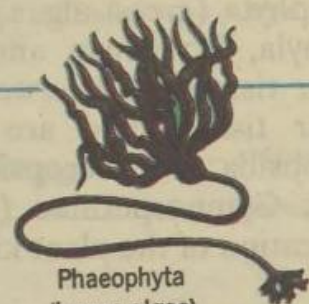
Cyanophyta
(blue-green algae)



Rhodophyta
(red algae)



Chrysophyta
(diatoms)



Phaeophyta
(brown algae)



multicellular. They make their own food and lack the ability to move from place to place.

4. **Kingdom Fungi:**

These multicellular organisms are made of eukaryotic cells. They do not move about. They obtain their food by absorbing it from dead or living organisms.

5. **Kingdom Animalia:**

Members of this kingdom are made of eukaryotic cells. Animals are multicellular. They move from place to place to obtain food. The food is then digested inside the body.

In this text we have used a two kingdom system. These two kingdoms are Plantae and Animalia. They include all the organisms. Viruses are treated separately because of their unique nature.

In (Fig. 9.8) is shown, how the plant kingdom is divided into groups and sub groups and how the various groups of plants are related to one another. Plant kingdom is first divided into two sub-kingdoms, Thallophyta and Embryophyta. Thallophytes are plants in which the plant body is a thallus. A thallus is a plant body not differentiated into root, stem or leaf. Their reproductive organs are unicellular and are not protected by vegetative or sterile cells. Thallophytes include, Fungi and Algae. Fungi are thallophytes without chlorophyll and algae are thallophytes with chlorophyll. Plants in the sub-kingdom Embryophyta are characterized by the presence of an embryo and multicellular reproductive organs which are protected by sterile cells. Sub-kingdom Thallophyta and Embryophyta are divided into phyla which are shown in (Fig. 9.8).

Phylum Myxomycophyta and Eumycophyta are included in Fungi. In the group 'Algae' Phylum Cyanophyta (blue green algae), Rhodophyta (red algae), Chrysophyta (golden algae), Phaeophyta (brown algae), Euglenophyta and Chlorophyta (green algae) are included. In sub-kingdom Embryophyta, there are two phyla, Bryophyta and Tracheophyta. Bryophyte are embryophytes without vascular tissue e.g. liverworts and mosses. Tracheophytes are embryophytes with vascular tissues and are divided into four sub-phyla: Psilopsida, Lycopsida, Sphenopsida and Pteropsida. Pteropsida are divided into three classes, Filicinae (ferns), Gymnospermae (conifers) and Angiospermae (flowering plants). This classification of the plant kingdom is based on evolutionary-relationship.

FAMILIES OF ANGIOSPERMS

Family Cruciferae (Mustard Family).

This family is now known as Brassicaceae. It is world-wide in distribution. There are about 350 genera and 3,000 species. Its calyx consists of four sepals which are free. Corolla consists of four petals which are free and spread out to form a cross. Androecium consists of six stamens. Outer two stamens are shorter and inner four stamens are longer (Fig. 9.9). Gynoecium consists of two carpels which are united. Fruit is dry and dehiscent.

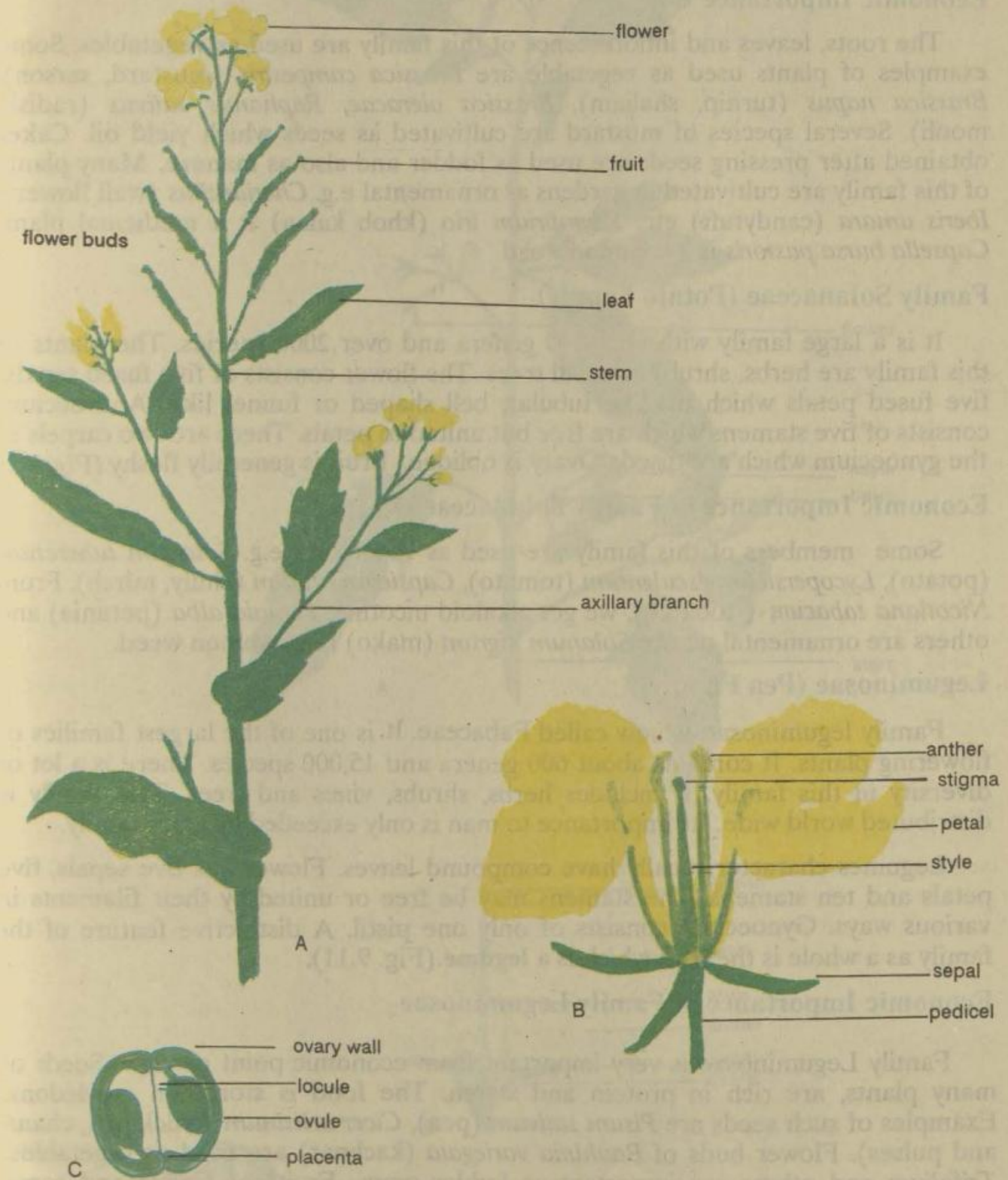


Fig. 9.9 *Brassica campestris* A. A Flowering Branch B. A Flower
 C. C.S. of ovary

Economic Importance

The roots, leaves and inflorescence of this family are used as vegetables. Some examples of plants used as vegetable are *Brassica campestris* (mustard, sarson), *Brassica napus* (turnip, shaljam), *Brassica oleraceae*, *Raphanus sativus* (radish, mooli). Several species of mustard are cultivated as seeds which yield oil. Cakes obtained after pressing seeds are used as fodder and also as manure. Many plants of this family are cultivated in gardens as ornamental e.g. *Cherianthus* (wall flower), *Iberis amara* (candytuft) etc. *Sisymbrium irio* (khob kalan) is a medicinal plant. *Capsella bursa pastoris* is a common weed.

Family Solanaceae (Potato Family)

It is a large family with about 90 genera and over 2000 species. The plants of this family are herbs, shrubs or small trees. The flower consists of five fused sepals, five fused petals which may be tubular, bell shaped or funnel like. Androecium consists of five stamens which are free but united to petals. There are two carpels in the gynoecium which are fused. Ovary is oblique. Fruit is generally fleshy. (Fig. 9.10).

Economic Importance of Family Solanaceae

Some members of this family are used as vegetables e.g. *Solanum tuberosum* (potato), *Lycopersicum esculentum* (tomato), *Capsicum annum* (chilly, mirch). From *Nicotiana tabacum* (tobacco), we get alkaloid nicotine. *Petunia alba* (petunia) and others are ornamental plants. *Solanum nigrum* (mako) is a common weed.

Leguminosae (Pea Family)

Family leguminosae is now called Fabaceae. It is one of the largest families of flowering plants. It contains about 600 genera and 15,000 species. There is a lot of diversity in this family. It includes herbs, shrubs, vines and trees. This family is distributed world wide. Its importance to man is only exceeded by grass family.

Legumes characteristically have compound leaves. Flower has five sepals, five petals and ten stamens. The stamens may be free or united by their filaments in various ways. Gynoecium consists of only one pistil. A distinctive feature of the family as a whole is the fruit which is a **legume**. (Fig. 9.11).

Economic Importance of Family Leguminosae

Family Leguminosae is very important from economic point of view. Seeds of many plants, are rich in protein and starch. The food is stored in cotyledons. Examples of such seeds are *Pisum sativum* (pea), *Cicer arietinum* (chick pea, chana and pulses). Flower buds of *Bauhinia variegata* (kachnar) are used as vegetables. *Trifolium* and others are important as fodder crops. Fruits of *Cassia* and some other members are used in medicines. Woods of many members e.g. *Dalbergia sissoo* (shisham) is used in making furnitures etc. Many plants are cultivated as ornamentals. Some ornamental plants of this family are: *Lathyrus odoratus* (sweet pea), *Cassia fistula* (amaltas), *Poinciana* (gold mohar), *Erythrina* (flame of the forest), *Mimosa pudica* (Lajvanti) and others. From legumes we also obtain oils,

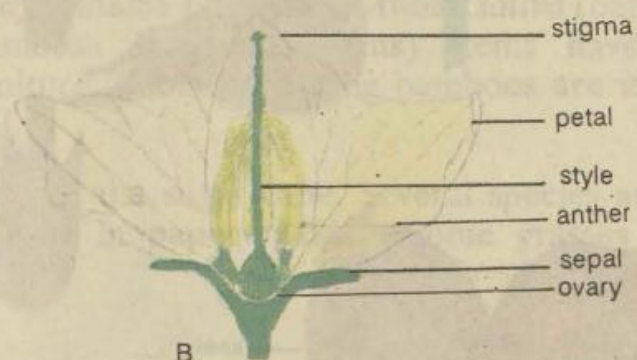
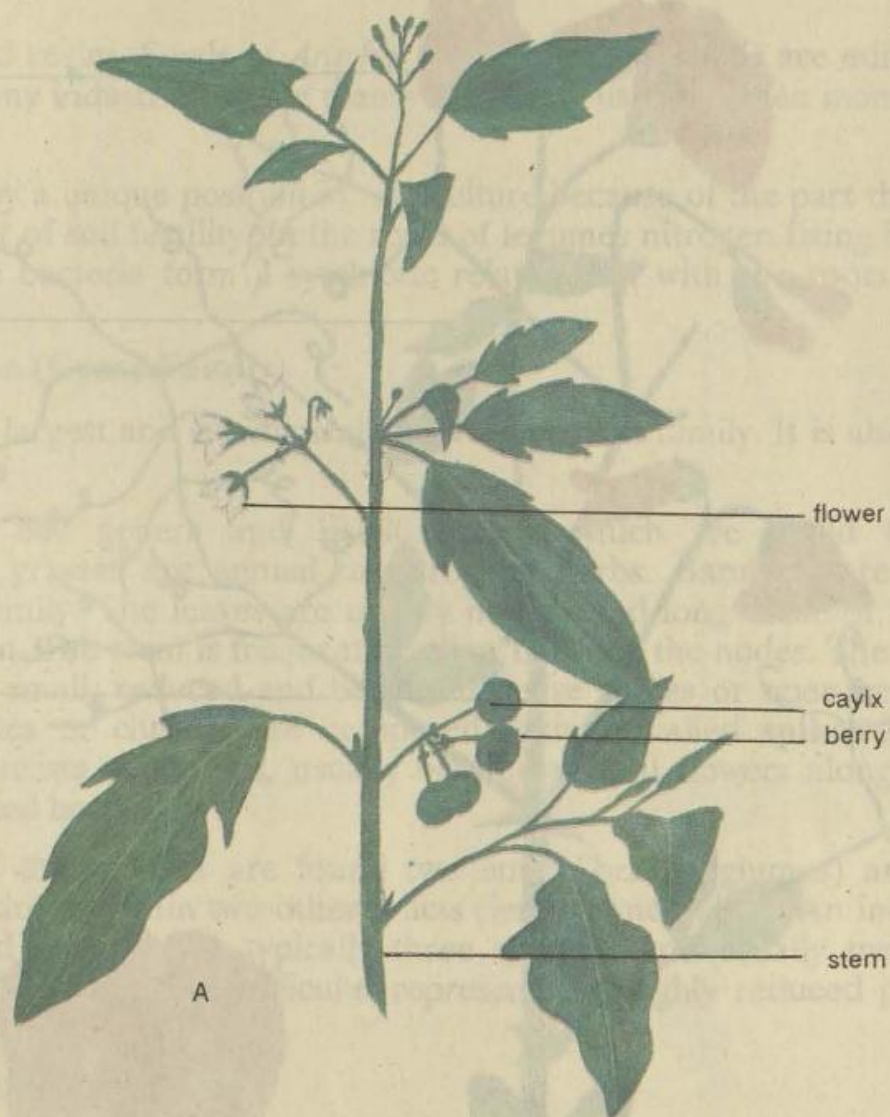


Fig. 9.10 *Solanum nigrum*. A. Flowering Shoot B. V.S. of flower C. C.S. of ovary

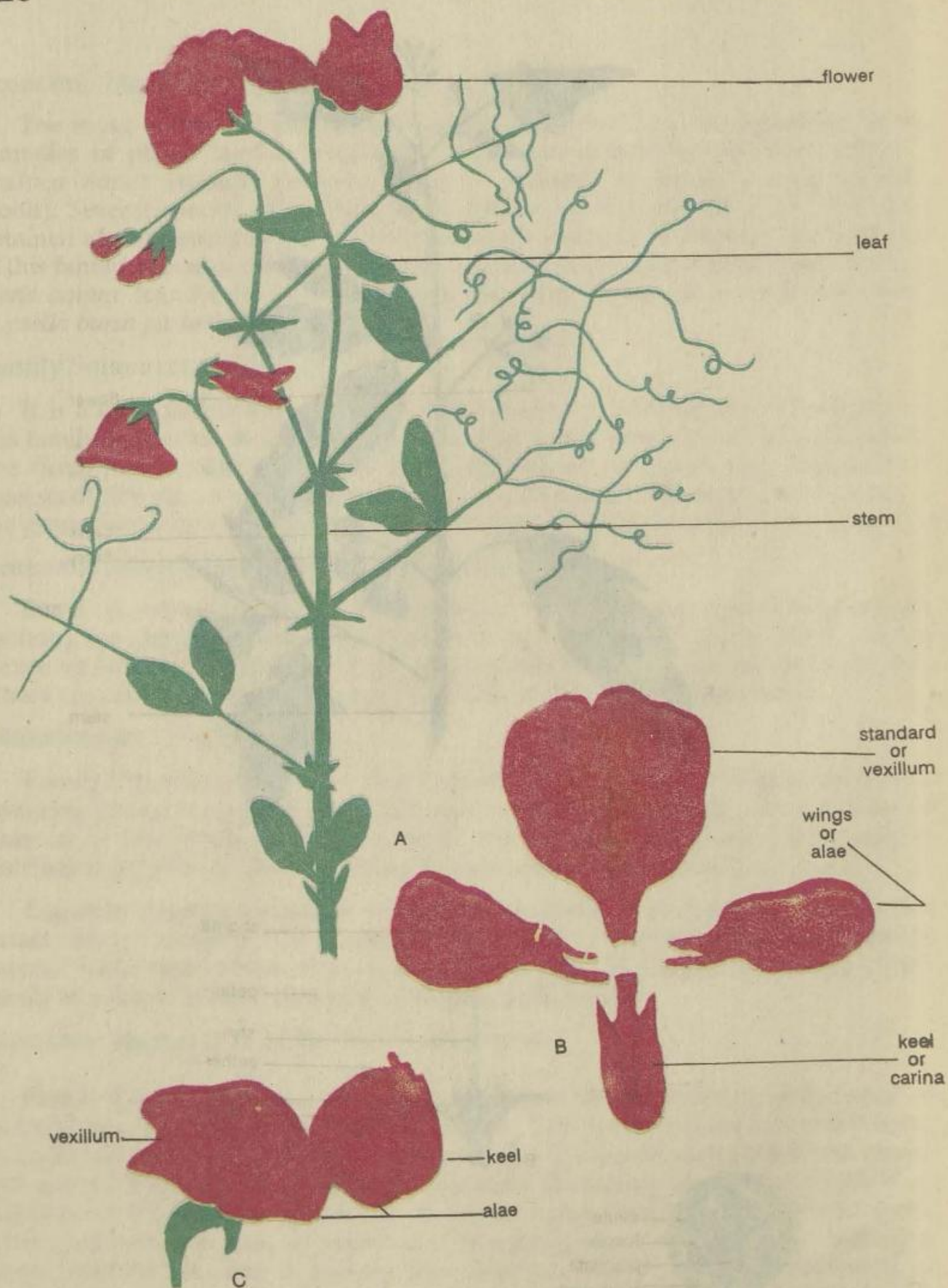


Fig. 9.11 *Lathyrus odoratus* A. A Flowering branch B. Corolla C. A Flower

proteins, gums and resins. Seeds of *Arachis hypogea* (moongphali) are edible and its oil is used in many industries. Some plants are widely used as green manure e.g. gueraa.

Legumes occupy a unique position in agriculture because of the part they play in the improvement of soil fertility. In the roots of legumes nitrogen fixing bacteria are present. These bacteria form a symbiotic relationship with the roots of this family.

Family Gramineae (Grass Family)

It is one of the largest and economically most important family. It is also called Poaceae.

It consists of 600 genera and 10,000 species which are world wide in distribution. Most grasses are annual or perennial herbs. Bamboos are woody members of this family. The leaves are usually narrow and long. Base of the leaf ensheathes the stem. The stem is frequently hollow between the nodes. The flowers of the grasses are small, reduced and borne on dense spikes or open branching clusters. Such spikes or clusters are composed of units called **spikelets**. Each spikelet in turn consists of an axis, usually bearing several flowers along with a number of specialized bracts.

At the base of the spikelet are found two empty bracts (glumes) and each flower is tightly enclosed within two other bracts (lemma and palea). An individual flower is composed of a carpel, typically three stamens and usually two scales (lodicules) below the ovary. The lodicules represent the highly reduced perianth (Fig 9.12).

Economic Importance of Family

This family has great economic importance. All the principal cereals belong to this family. Some of them are *Triticum aestivum* (wheat or gandum) *Oryza sativa* (rice or chawal), *Zea mays* (maize or makai), *Avena sativa* (oat or javi), *Hordeum vulgare* (jao). The Bambosa (Bamboos, bans) stems have endless uses in construction and in furniture. Shoots of young bamboos are used as food. Some bamboos are ornamental.

Saccharum officinarum is the sugar cane. Several species are useful as fodder for cattles. Other are used in paper making. Some grasses are cultivated for aromatic oils.

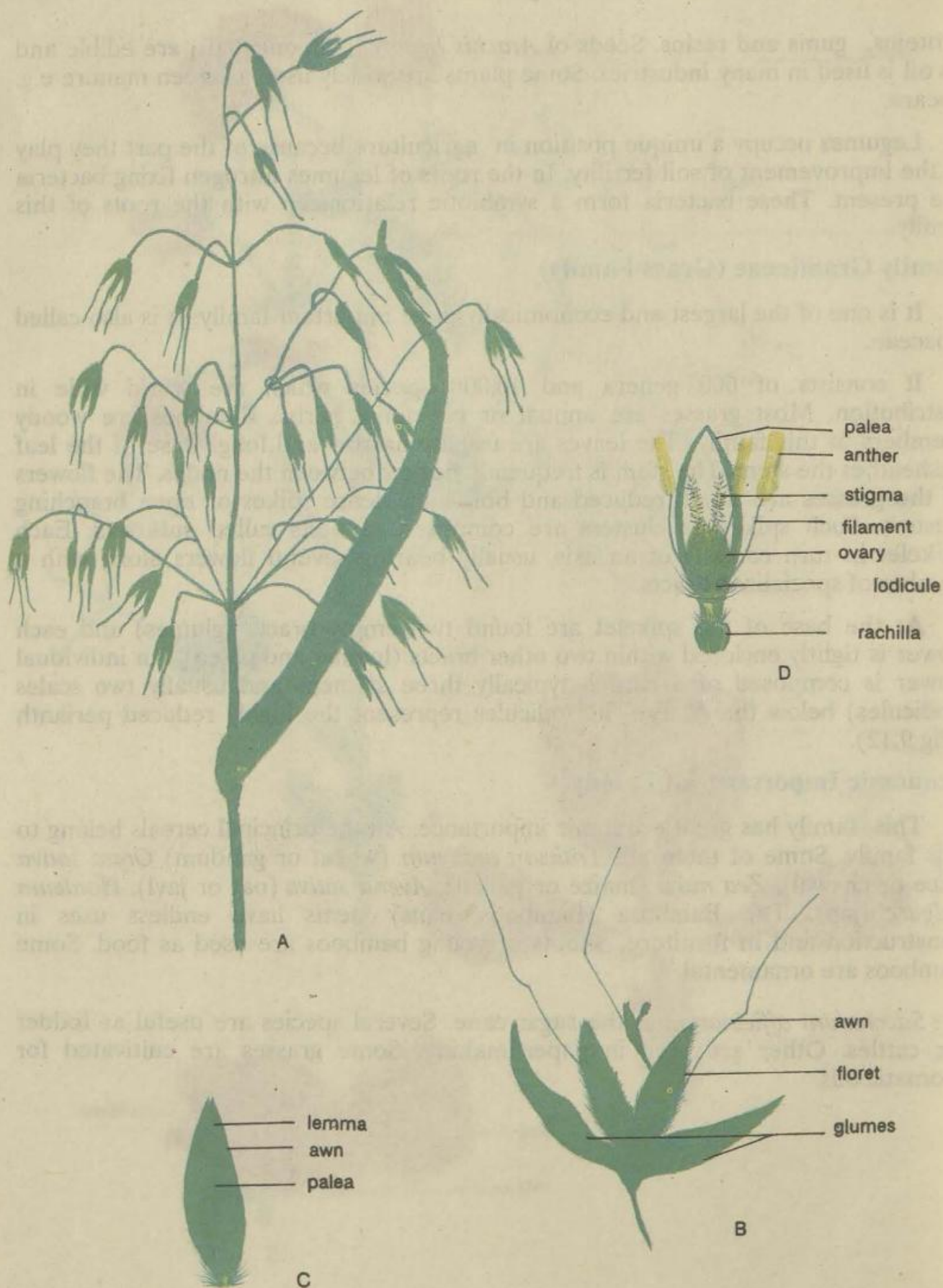


Fig.9.12 *Avena sativa* A. Inflorescence B. Spikelet C. Floret D. Opened flower

QUESTIONS

1. Describe the life cycle of a pine tree.
2. With the help of a diagram describe the structure of a flower.
3. What is inflorescence? Describe the common type of inflorescence in flowering plants.
4. Define pollination? How self pollination differs from cross pollination? Which pollination is more advantageous to plants?
5. Describe the life cycle of an angiosperm.
6. Describe structure and development of male and female gametophyte of a flowering plant.
7. How pollen tube had played an important role in the success of flowering plants?
8. Give an account of relationships of gymnosperms with pteridophytes and angiosperms.
9. Define the following terms:
 - (a) autotrophs
 - (b) heterotrophs
 - (c) protista
 - (d) monera
 - (e) species
10. Why it is necessary to classify and clearly name living things?
11. Name some organisms which are difficult to assign either to plant kingdom or animal kingdom.

12. The following are all classification groups: family, genus, kingdom, order, phylum, species, class. Rearrange these so that they are in proper order of sequence from the smallest grouping to the largest.
13. Give biological classification corn plant.
14. Give general characters and the economic importance of the following families:
 - (a) Cruciferae
 - (b) Solanaceae
 - (c) Gramineae
 - (d) Leguminosae

DIVERSITY IN FORM: ANIMALS THE INVERTEBRATES

10

All animals present on earth, whether in the present times or in the past, belong to the **kingdom Animalia**. On the basis of their structure, physiology, reproduction, development, biochemical processes, inheritance and evolutionary history, various kinds of animals are first arranged into major groups known as phyla and then each phylum is systematically divided towards the lower grade in the following manner:

Phylum

class

order

family

genus

species

A phylum therefore, is a bigger group in which all the members resemble one another in some fundamental characteristics. As we go down the ladder of classification, we find that members of smaller groups share more characteristics till we reach the species level. The members of a species are all very similar in their external and internal characteristics and reproduce among themselves. They have a definite number of chromosomes in their cells, live under similar conditions and show similar kind of behaviour. Therefore, species is the smallest unit of classification and is very important from the taxonomic point of view.

An animal may have many local names and these names may be different in different areas, but biologically speaking, each type of animal has been given a name that is internationally accepted and is given the same name, no matter in which country or which part of the world it occurs. In this method, each animal or plant name has two parts. The first part represents the genus and is written with a

capital letter and the second part represents the species and begins with a small letter. This scheme is known as **binomial nomenclature**. All names are in Latin. According to this method of nomenclature and scheme of classification, we can take the example of a common frog found in various parts of Pakistan which is classified as follows:

Phylum Chordata

Sub Phylum Vertebrata

Class Amphibia

Order Anura

Family Ranidae

Genus *Rana*

Species *tigrina*

Therefore, its biological name is *Rana tigrina*. Similarly you can classify any other animal.

Animals can generally be divided into two major groups: **Invertebrates** and **Vertebrates**. This division is based on the presence of supporting rod known as Vertebral column in Vertebrates, which is absent in invertebrates. All Vertebrates are grouped under phylum chordata, while invertebrates have been grouped under phyla Protozoa, Porifera, Coelenterata, Platyhelminthes, Nematoda, Arthropoda, Mollusca and Echinodermata. The invertebrate phyla will be described below, while phylum chordata will be dealt with in the next chapter.

THE UNICELLULAR ANIMALS

Phylum Protozoa

There is no doubt about it that the earliest forms of life were simple unicellular organisms and in that respect protozoans must be considered the earliest animals. Many of these have survived the longest geological periods with very little change. In the simplest form, protozoans have bodies composed of a single mass of cytoplasm or unit rarely reaching more than 1 mm across, containing all the structures found in a typical cell such as nucleus, mitochondria, etc. But the cell may attain complexity and may have intricate parts because, after all, this cell is the whole animal and it has to meet all the demands of life, such as nutrition, respiration, locomotion, homeostasis reproduction and other such functions. *Amoeba* is a typical example of a simple unicellular animal (Fig. 10.1a). *Paramecium* (Fig. 10.1b) is a much more complicated protozoan, but still its body

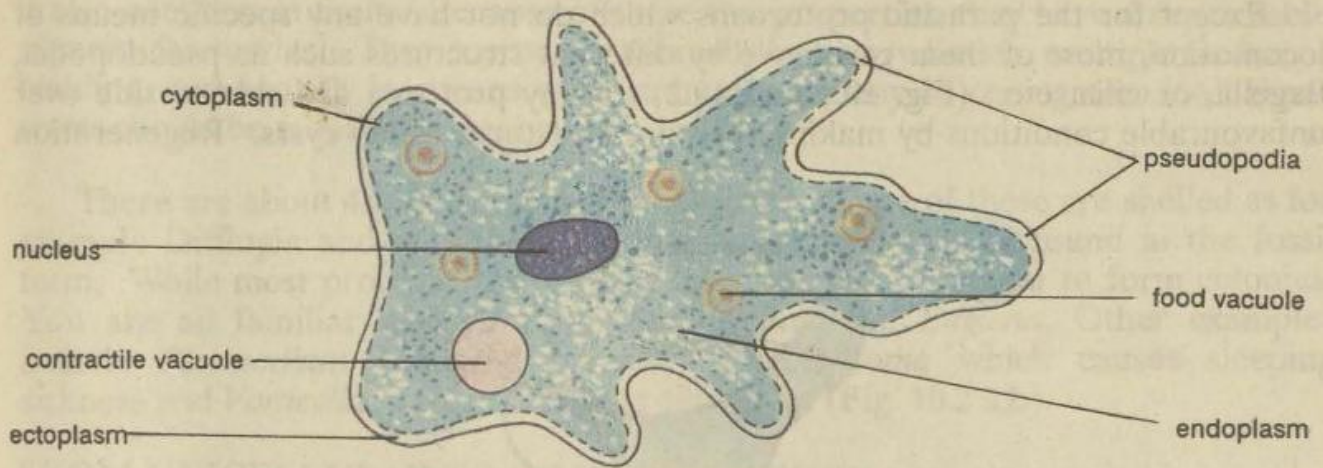


Fig. 10.1 (a) Amoeba

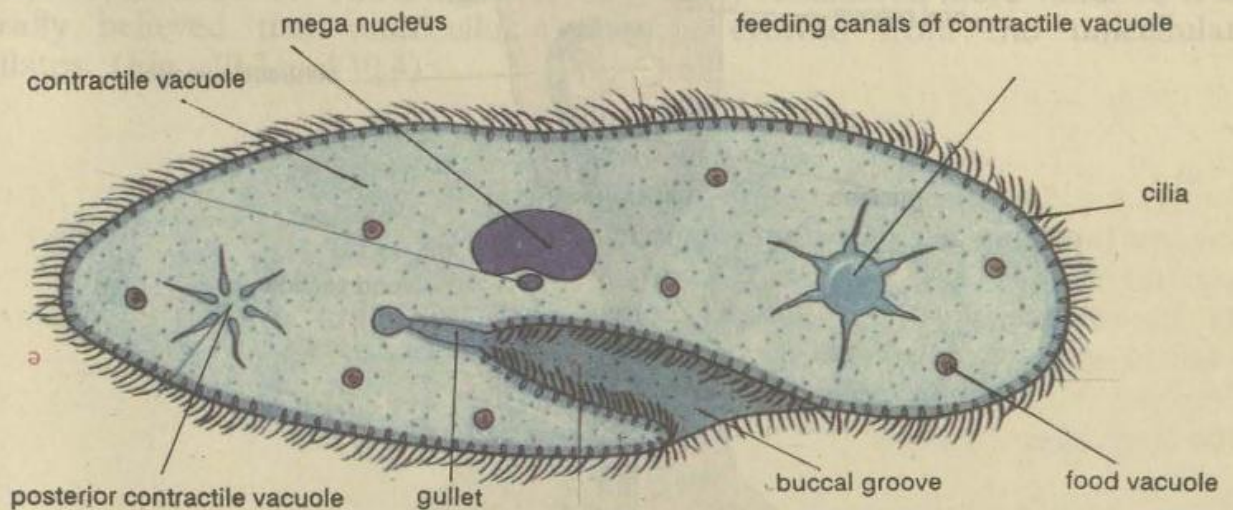


Fig. 10.1 (b) Paramecium

never attains the complexity found in larger animals. Protozoans are mostly aquatic, fresh water or marine, but some are found in damp places and a number of them are parasites. In spite of their different kinds of habitats, they rarely show any obvious structural adaptations in the way larger animals do. Thus, it is difficult to make inferences about their mode of life merely from their structure.

Except for the parasitic protozoans which do not have any specific means of locomotion, most of them can move by different structures such as pseudopodia, flagella, or cilia, etc. (Fig. 10.1 and 10.2). Many protozoa are able to tide over unfavourable conditions by making resistant structures called **cysts**. Regeneration

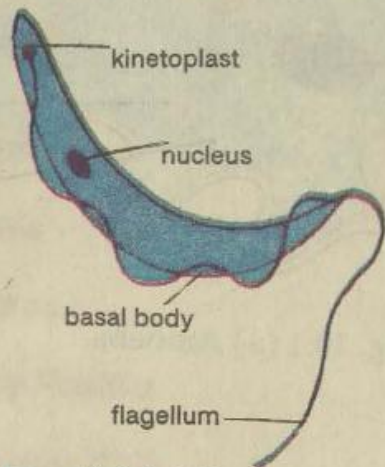


Fig. 10.2 (a) Trypanosoma.

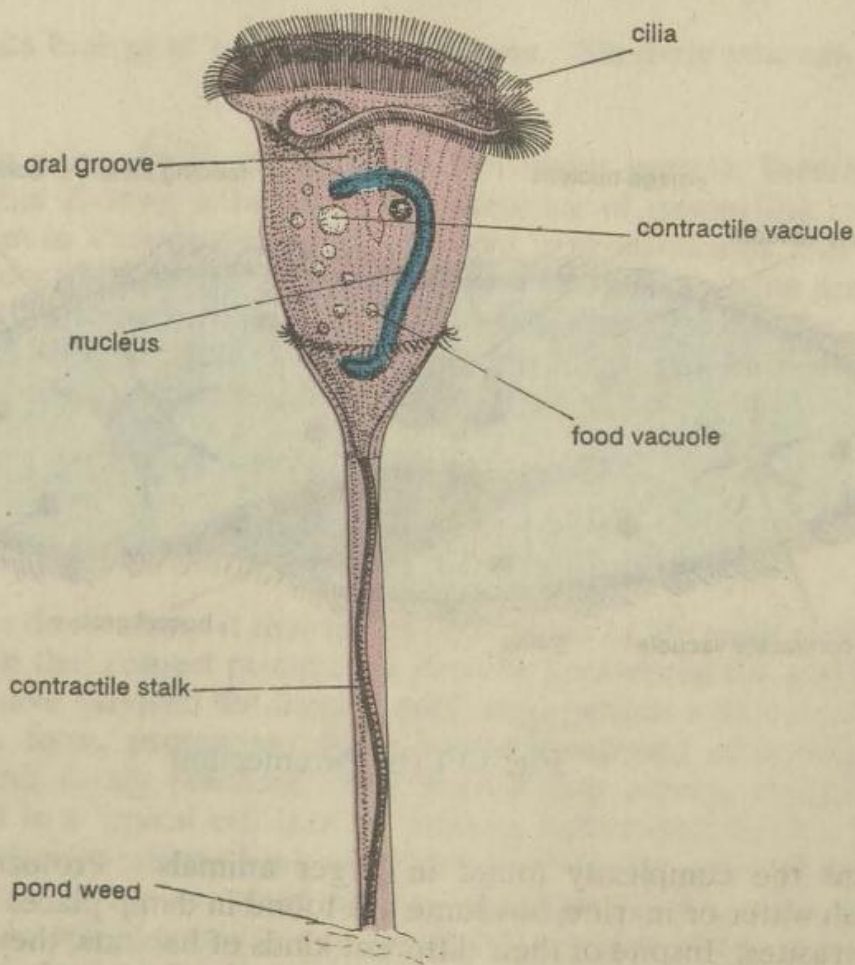


Fig. 10.2b Vorticella

is also common in them. Because of these two properties, they have a remarkable capacity for survival. They reproduce asexually by binary fission, multiple fission or budding, and sexually by means of isogamy, an-isogamy or conjugation. All these terms should be familiar to you by now.

There are about 45,000 species of protozoans. Some of these are shelled as for example *Diffugia* and only these kinds of protozoans can be found in the fossil form. While most protozoa live solitary lives, some get together to form colonies. You are all familiar with *Amoeba*, *Paramecium* and *Euglena*. Other examples include *Plasmodium* (malarial parasite). *Trypanosoma* which causes sleeping sickness and *Vorticella*, a colonial sessile ciliate etc. (Fig. 10.2 a,b).

FROM UNICELLULAR TO SIMPLE MULTICELLULAR

The most primitive multicellular animals are the sponges and then the coelenterates. The origin of sponges is a subject of much controversy. According to a popular view, a flagellate of genus *proterospongia* closely resembles a sponge. So, *Proterospongia* is considered to represent first stage of evolution in the direction of sponges. According to another view, the sponges, like Metazoa, might have evolved from colony forming protozoan flagellates.

Haeckel derived multicellular organisms, Metazoa, from hollow Volvox-like ancestor while, solid colony form such as *Synura* was considered by other biologists as the probable ancestor. The latter view is generally considered more valid. So it is generally believed that multicellular animals evolved from the unicellular flagellates. (Fig 10.3 and 10.4)

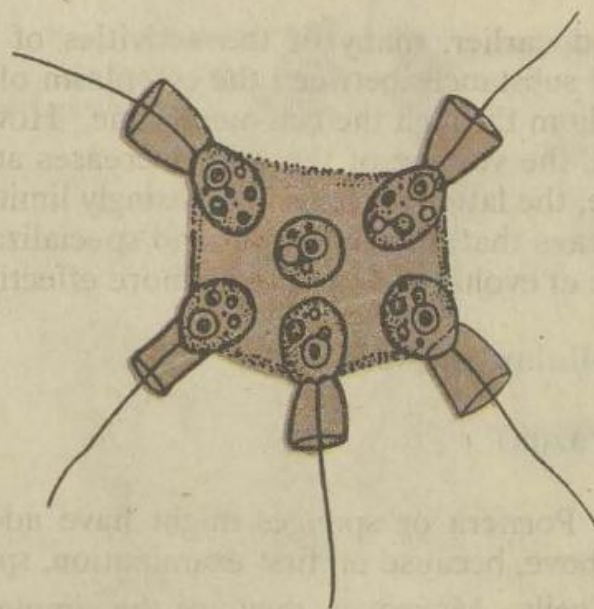


Fig. 10.3 *Proterospongia*

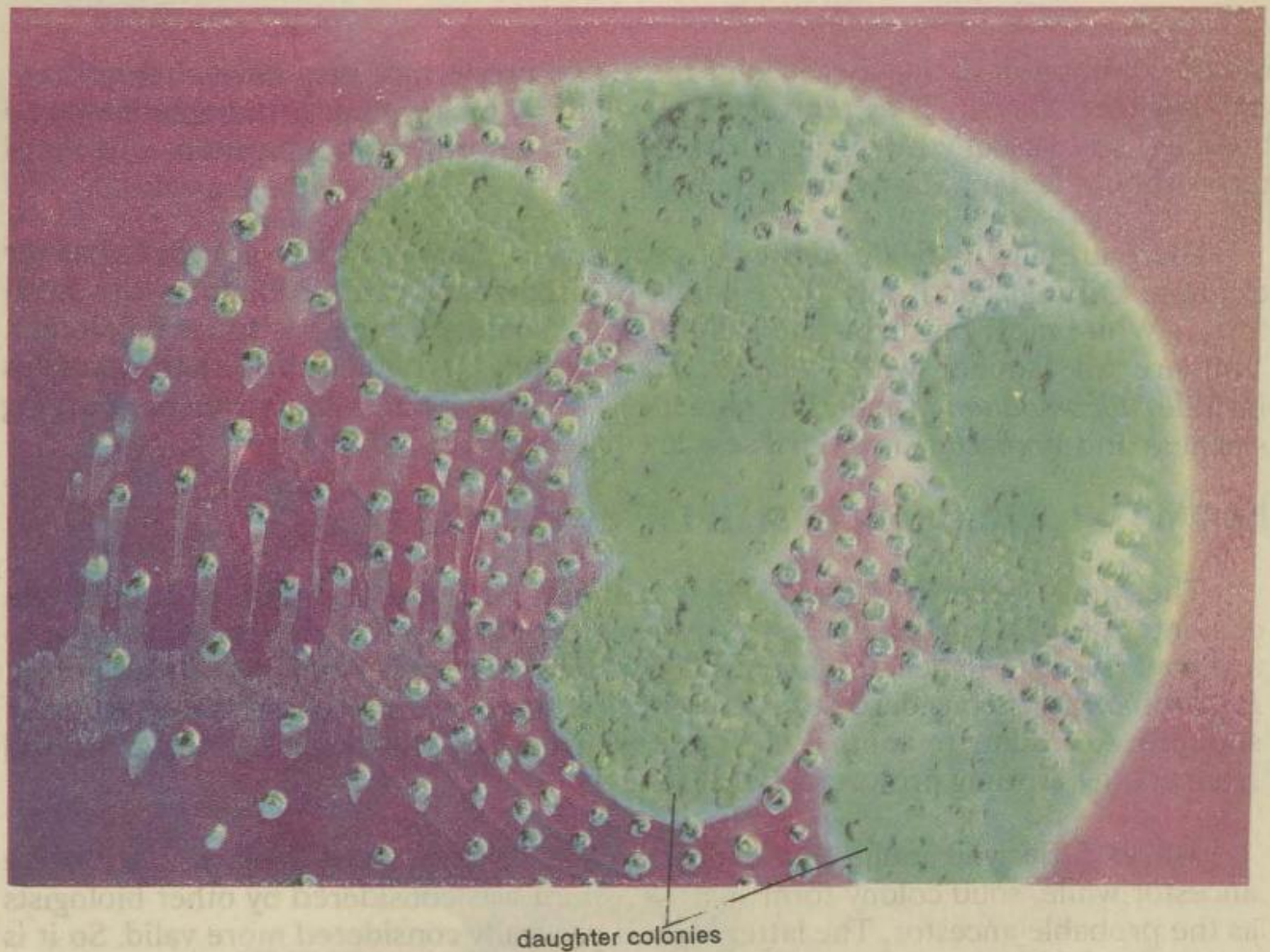


Fig. 10.4. Colony of volvox containing daughter colonies.

As we have studied earlier, many of the activities of unicellular organisms involve the exchange of substances between the cytoplasm of the organism and the surrounding liquid medium through the cell membrane. However, with the growth in size of the organism, the volume of the body increases at a faster rate than its surface area, and hence, the latter becomes increasingly limiting to supply the body requirements. This means that differentiation and specialization must accompany the large size. This line of evolution seems to be more effective.

The Simplest Multicellular Animals

Phylum Porifera (Parazoa)

It is probable that Porifera or sponges might have adopted the first line of evolution mentioned above, because on first examination, sponges appear to be no more than a colony of cells. Moreover, they are the simplest and are considered the most primitive of the multicellular animals (Fig 10.5.).

Sponges are made up of several types of cells but these cells are neither

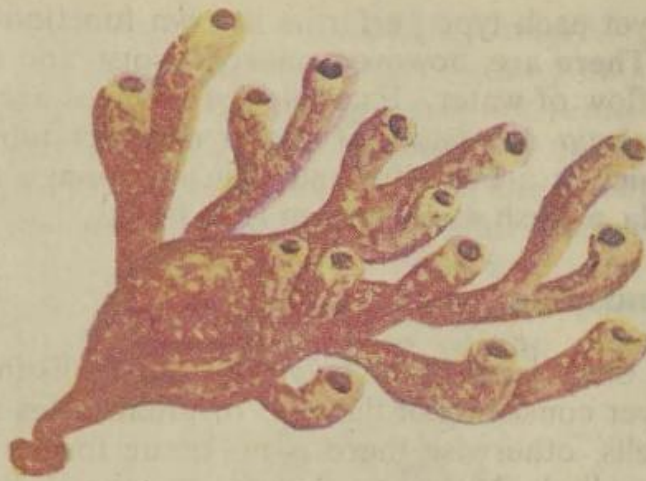


Fig. 10.5 A sponge, *Sycon*

organized into tissue layers nor as organs. Perhaps due to this reason most of them do not have a well defined body plan. They are all aquatic, mostly marine and sessile. Their body is perforated by numerous pores (ostia) through which water enters, circulates through various channels or a simple main cavity and goes out by a large opening, the **osculum**. This system of circulation of water is called **canal system**. Most of them are provided with internal skeleton of calcareous or siliceous material. Reproduction takes place both asexually, by the formation of buds and sexually, by means of ova and sperms. Some sponges have a remarkable ability of regeneration from a small fragment. Although sponges have a large number of

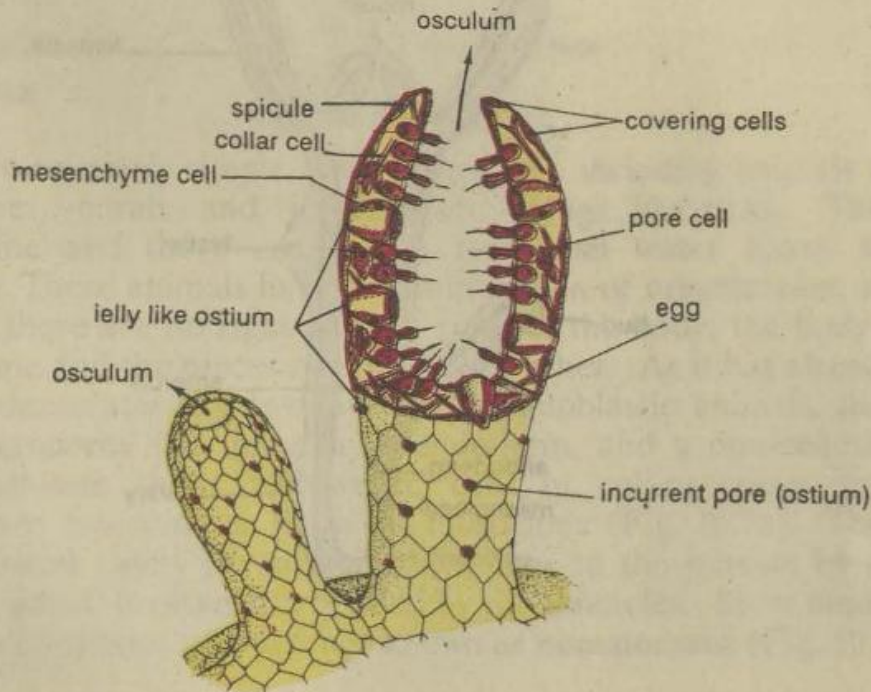


Fig. 10.6 Part of a colony of a simple sponge, the upper part is cut away to show the structure.

different kinds of cells, yet each type performs its own function and there is very little interdependence. There are, however, neurosensory and neuron cells which seem to coordinate the flow of water. Examples of sponges are *Sycon*, the typical marine sponge; *Leucosolenia* consisting of group of erect tubes; *Euplectella* or Venus flower basket which is a beautiful and delicate sponge made up of glassy frame-work, and spongilla, a fresh water sponge (Fig 10.6).

The Diploblastic Organization

In most sponges, the outer layer of the body wall can be distinguished as surface epithelium or dermal layer consisting of flat cells or **pinacocytes** and inner lining of **choanocytes** or collar cells, otherwise there is no tissue formation. But in other multicellular animals called **Metazoa** there is more differentiation and specialization of cells, more tissue and organ formation, more interdependence and more division of labour.

The degree of differentiation and specialization met within the metazoa is extremely variable and results in the recognition of different grades of structure. These form the basis of classification of the multicellular animals into two main

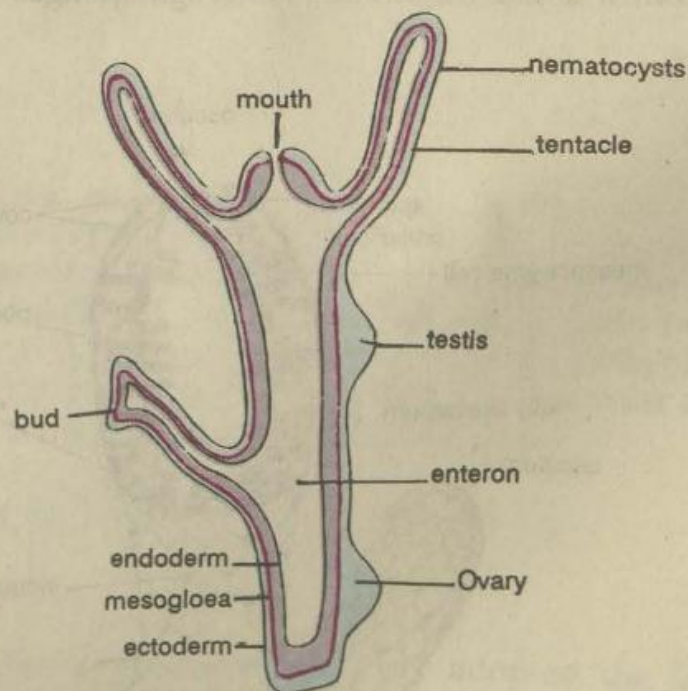
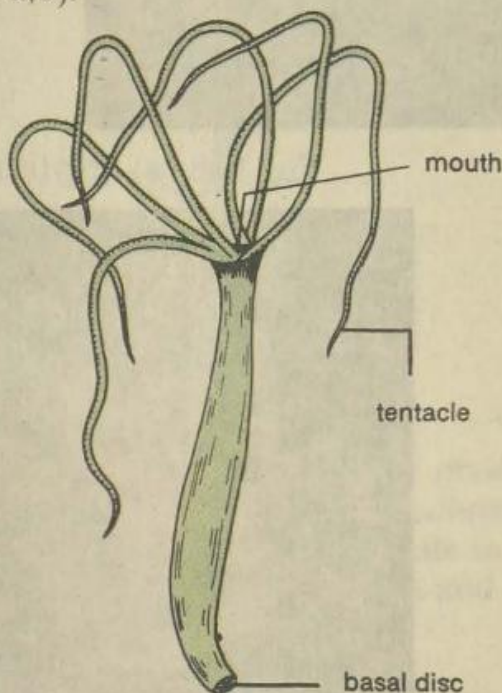


Fig. 10.7 (a) Longitudinal section of Hydra.

groups, the **Diploblastica**, the two-layered animals, comprising the coelenterates, and the **Triploblastica**, the three-layered animals forming majority of the groups. The distinction between the two major groups does not remain very sharp in the higher coelenterates. Although diploblastic animals are undoubtedly the simplest of the metazoa, they are much more complex than the sponges. An important aspect of the diploblastic animals is that their body wall consists of two main layers of cells; an outer layer, the **ectoderm** and an inner layer, the **endoderm**. There usually is a jelly-like layer called **mesogloea** between the two but this is in most cases non-cellular. The general organization of the diploblastic animals is illustrated by Hydra (Fig 10.7 a,b).



The Two-layered Animals Phylum Coelenterata

Fig. 10.7 (b) Hydra

Coelenterates are relatively simple aquatic metazoa, including animals such as Hydra, sea-anemones, corals and jellyfish etc. (Figs. 10.7, 10.8). They are predominantly marine and there are only a few fresh water forms such as Hydra (Figs. 10.7 a,b). These animals have a primitive plan of organization, showing radial symmetry i.e., there are no right and left sides of the body; the body can be cut across by any plane and the pieces resemble each other. As it has already been pointed out, the coelenterates are two-layered or diploblastic animals, the outer layer is known as ectoderm, the inner layer endoderm, and a non-cellular layer called mesogloea between them. However, cells or cell-processes from the ectoderm or endoderm can come to lie in the mesogloea (Fig. 10.7a). There is a sac-like internal digestive cavity or enteron that opens to the outside by a single aperture, the mouth, which is often surrounded by the tentacles. Most animals are provided with organs of offense and defence known as **nematocysts**. (Fig. 10.7, 10.9).

Most coelenterates are often found joined together to form colonies, the units of which are termed **zooids**. These zooids are not all alike and two main types are common; the **hydroids** or **polyps** which are the feeding zooids, and umbrella like

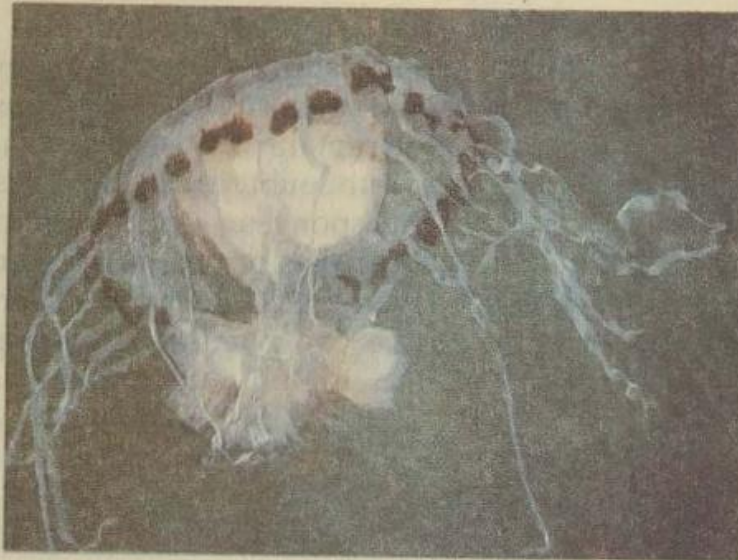


Fig. 10.8 (a) Jellyfish



Fig. 10.8 (b) Sea anemone

medusae, which are specialized to carry the reproductive organs. Some coelenterate colonies show a great variety of zooids, a phenomenon known as **polymorphism**. Many coelenterates show an alternation of generations. In this case the sedentary hydroid or polyp type reproduces asexually by budding, yielding progeny of medusae type. Medusae reproduce sexually to form offspring that are hydroids. For some genera, such as *Hydra* there is no alternation of generations and they exist only in the polyp form while others exist only in the medusa form as in the jellyfish (Fig. 10.8(a)).

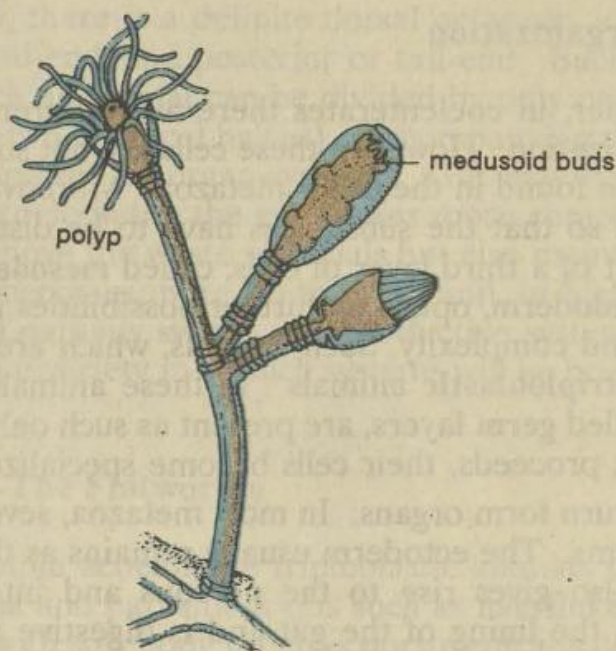


Fig. 10.9 Obelia

Many coelenterates, such as corals (Fig. 10.10) produce a hard exoskeleton made up of calcium carbonate. It is secreted by ectodermal (epidermal) cells that take lime from the sea water. The skeleton of corals in the tropical oceans has been responsible for the formation of large coral reefs and even small islands.

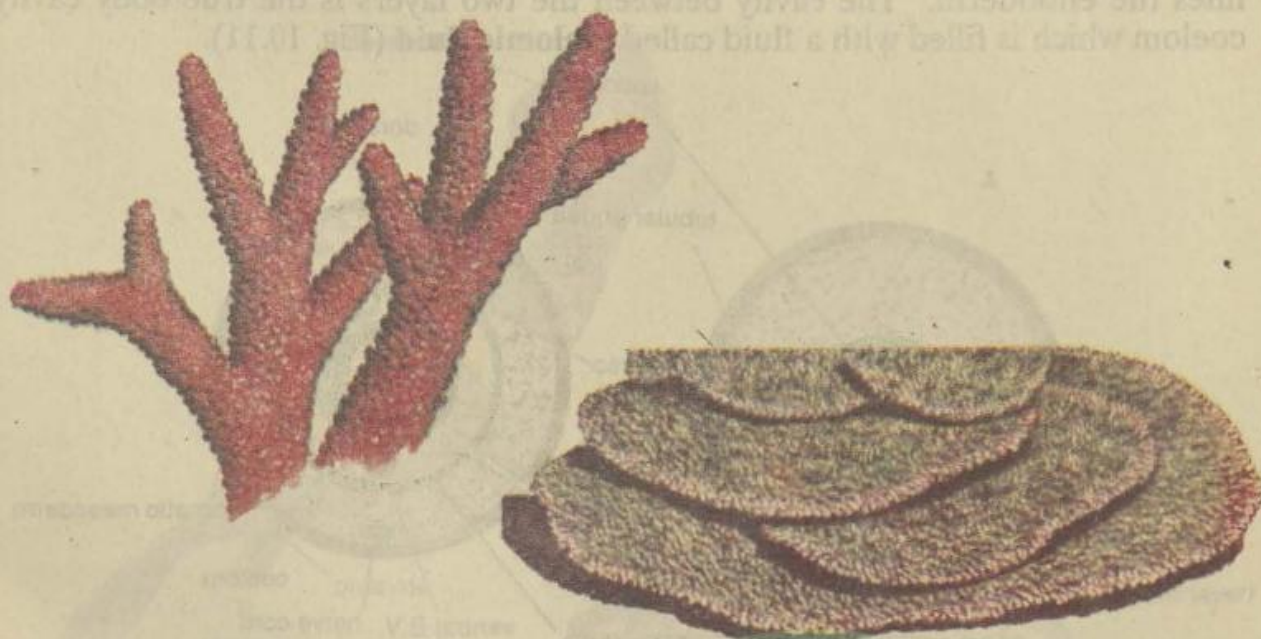


Fig. 10.10 Various kinds of dried corals

Triploblastic Organization

As seen earlier, in coelenterates there are different types of cells with some degree of specialization. However, these cells are not so aggregated to form tissues and organs as are found in the other metazoa. Moreover, the coelenterates lack a transport system so that the substances have to be distributed by diffusion alone. The development of a third layer of cells, called **mesoderm**, which lies between the ectoderm and endoderm, opens up further possibilities in terms of increase in size, differentiation and complexity. Such animals, which are built on the three-layered plan, are called **triploblastic** animals. In these animals, the three layers of cells, which may be called **germ layers**, are present as such only in the embryo because, as the development proceeds, their cells become specialized and rearranged to form tissues which in turn form organs. In most metazoa, several organs join together to form organ-systems. The ectoderm usually remains as the outer protective layer of the body, and also gives rise to the nervous and integumentary systems. The endoderm forms the lining of the gut and is digestive and absorptive in function. Mesoderm gives rise to the reproductive, muscular, skeletal and circulatory systems etc.

In some of the relatively simple three-layered animals there is no body cavity or coelom and the mesoderm forms a loose, cellular tissue, called mesenchyma or parenchyma, which forms a packing around all the internal organs. Such animals are called **acoelomata** while the others possessing a true body cavity or coelom are called **coelomata**. In the latter type the mesoderm splits into two layers. The outer is known as somatic layer which underlies the ectoderm and inner splanchnic layer lines the endoderm. The cavity between the two layers is the true body cavity or coelom which is filled with a fluid called **coelomic fluid** (Fig. 10.11).

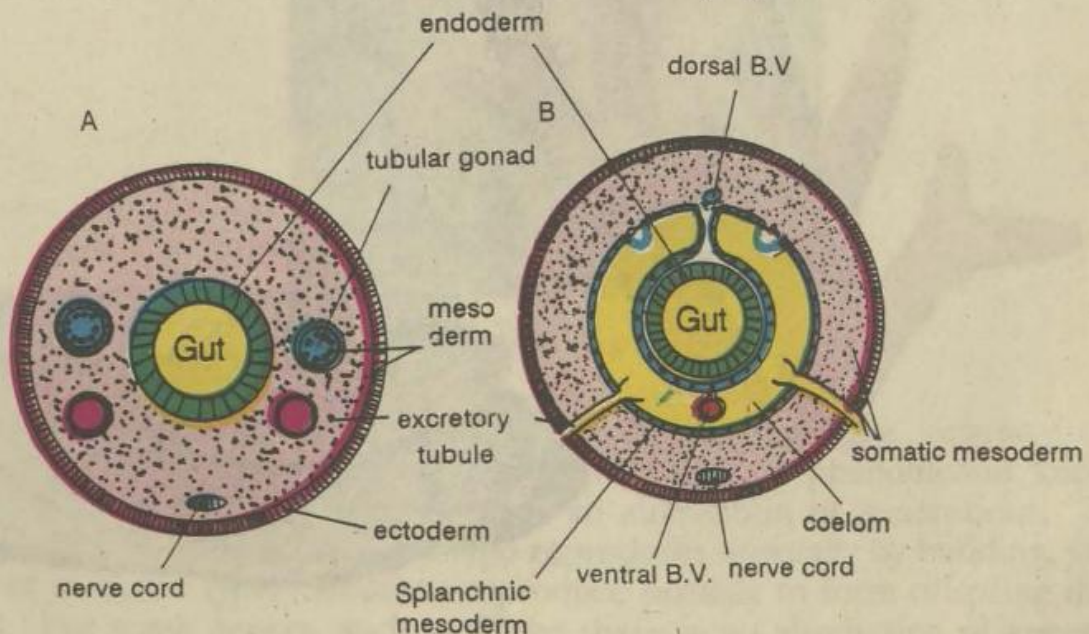


Fig.10.11 Diagrammatic transverse region through A, a generalised Acoelomate; B, a generalised coelomate.

In most of the metazoa, there is a definite dorsal or upper, a ventral or lower surface, the anterior or head-end, and posterior or tail-end. Such animals exhibit bilateral symmetry (in which an animal can be divided by only one longitudinal or vertical imaginary line into two identical halves). Accompanying these changes are the specialization and complexity of organ-systems. Gut may be simple in some acoelomates. However in coelomates, the gut attains more complexity. Excretory organs not only serve to remove the waste materials but also maintain homeostasis. The neuro-sensory system becomes more centralized, and, in higher forms, leads to the formation of central nervous system. Reproductive system also gets much more complicated. The great variety in all such systems will be briefly mentioned in the respective groups.

Phylum Platyhelminthes- The Flatworms

These are relatively simple acoelomate triploblastic animals that include free-living forms such as planaria and parasitic forms such as liverfluke and tape-worm, etc. All these animals are with soft body which is dorsoventrally compressed and is bilaterally symmetrical. There is no coelom or body cavity because the space between the body wall and the various organs is filled with a connective tissue known as mesenchyma or parenchyma. The enteric canal may be highly developed in the free living forms such as *Planaria* (Fig. 10.12), or it may be rudimentary or

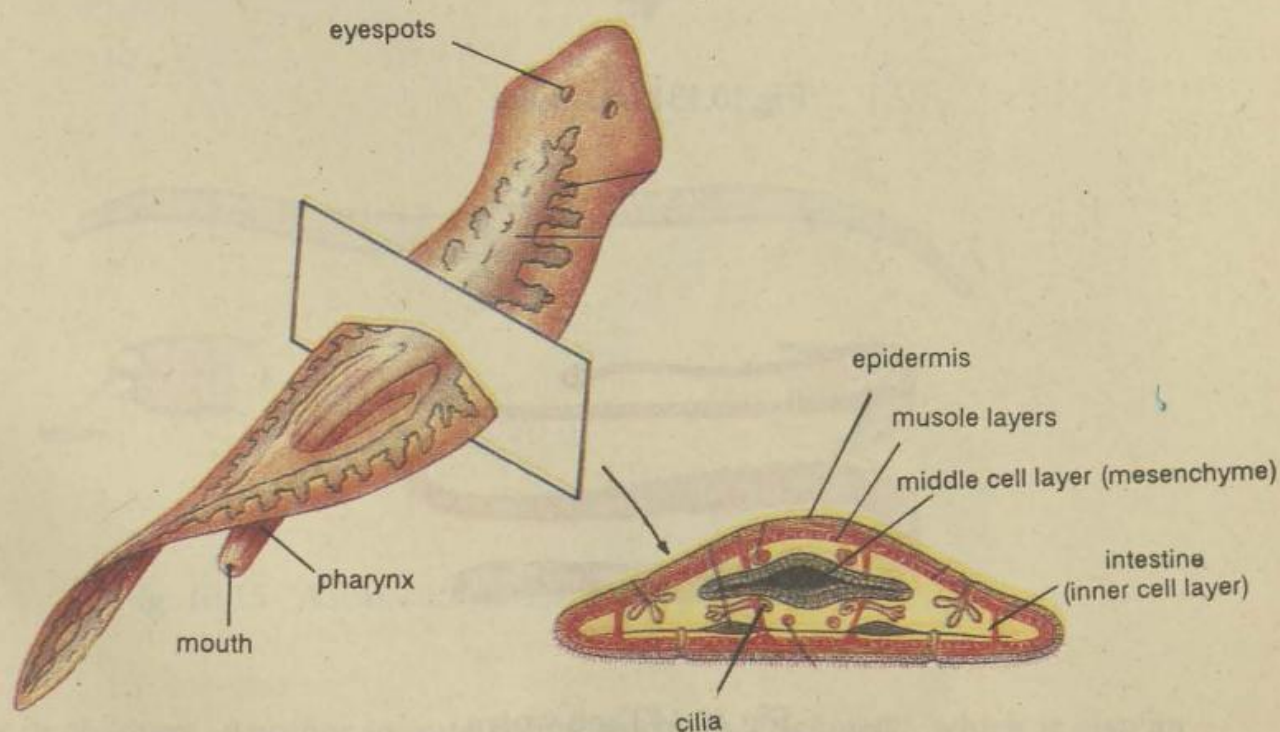


Fig. 10.12 Planaria and its cross section.

absent in the parasitic forms due to parasitic mode of life. There is however always one opening as mouth, the anus being absent. There is no blood vascular system. There is a well developed excretory or protonephridial system, containing **flame cells**. The reproductive system of flatworm is quite complicated. Majority are hermaphrodite. The eggs are provided with yolk and they are enclosed in thick covering. Development may be direct or may include metamorphosis.

Flatworms are quite widely distributed. They occur on land, in fresh water and sea, but many of them have adapted to a parasitic mode of life. If the parasite remains on the surface of the body of the host, it is called **ectoparasite** and if it gets into the body, it is called **endoparasite**. Two types of very common endoparasites are the liverflukes and tapeworms. A common liverfluke (*Fasciola hepatica*) lives in



Fig.10.13 Liver-fluke

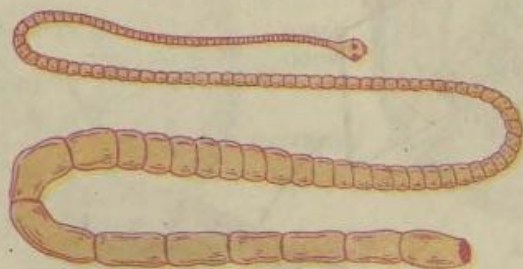


Fig.10.14 Tape-worm.

the bile duct of sheep and has a complicated life history, having snail as an intermediate host. The common tapeworm (*Taenia solium*) is a parasite in the intestine of man and in this case the intermediate host may be pig or cattle (Fig. 10.13 & Fig. 10.14).

Phylum Nematoda - The Roundworms

These animals have a round, cylindrical body pointed at both ends. One of the body differences, in comparison with the previous phyla, is a definite alimentary canal which is in the form of a simple tube with mouth at the anterior end and anus at the posterior end. The body cavity is a **pseudocoelom** (**pseudocoel**) which is a remnant of blastocoel. There is no blood vascular system. The excretory organ is somewhat unique, consisting of modified cells with internal canals fusing at the anterior end to form a single tube that empties to the exterior by an excretory pore. The nervous system is made up of a nerve ring surrounding the pharynx, from which nerve cords and fibers extend in various directions innervating the muscle cells and sense organs. The muscular layer is not continuous but is divided into four longitudinal quadrants, two dorso-lateral and two ventrolateral. Sense organs consist of sensory papillae present on the finely toothed lips at the anterior end. Most animals are unisexual.

Nematodes are quite abundant but they are not very conspicuous as a group because most of the free-living species and plant parasites are microscopic or very small in size. Many of the nematodes are parasites, some of which are large, e.g., *Ascaris lumbricoides* (Fig. 10.15), which is human intestinal parasite present

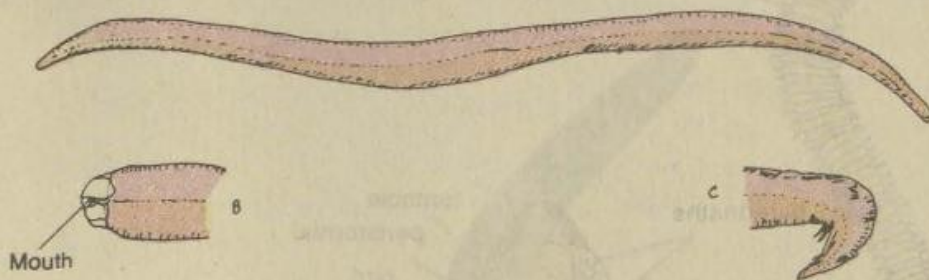


Fig. 10.15 *Ascaris*: its anterior and posterior end.

especially in children. Another minute round worms is *Trichinella*, which is also an intestinal parasite. Guinea worm (*Dracunculus*) causes abscesses on the skin of arms or legs.

Phylum Annelida-The Segmented Worms.

The Annelida includes segmented worms in which the body is metamerically segmented, which means that both internal organs and body surface is divided into segments by means of transverse partition called **septa**. The body is covered with a thin cuticle. The body wall is muscular in which there is an outer layer of circular muscles and inner layer of longitudinal muscles. Of all the groups studied so far, annelids constitute the first group in which there is a definite blood vascular system, which is the main transporting system of the body. The digestive tube, the principal longitudinal blood vessels, and the nerve cord extend without interruption throughout the length of the body. As annelids are coelomates, there is a true body cavity or coelom, lying between layers of mesoderm, but owing to the transverse partitions or septa it is uniquely separated into compartments. However, due to the spaces or apertures around the alimentary canal, the neighbouring coelom chambers communicate with each other and so does the coelomic fluid. The excretory organs consist of simple or highly convoluted tubes called **nephridia** which are segmentally repeated. Annelids possess a characteristic central nervous system, having a dorsal pair of cerebral ganglia and a ventral nerve cord, having a pair of ganglia in each segment from which nerves are **given off** to various parts of the segment. Annelida, however, in spite of being so well specialized and organized, lack definite respiratory organs, found in other higher animals. They use the moist skin for the exchange of respiratory gases. The sexes may be separate or united. Development may be direct or indirect through a trochophore

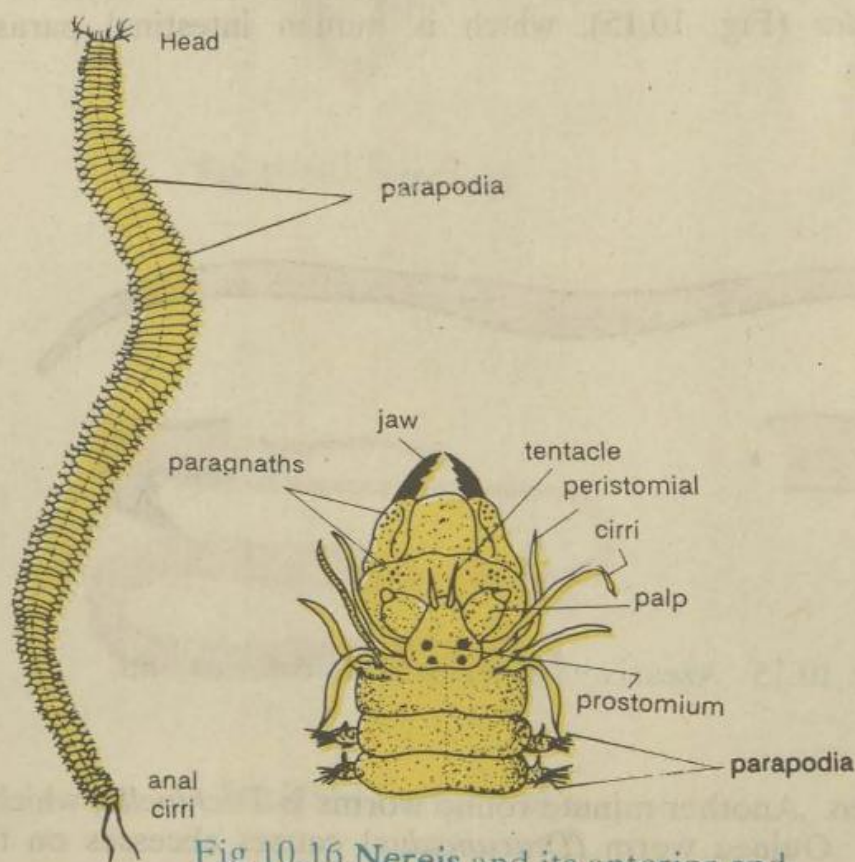


Fig 10.16 Nereis and its anterior end.

(trochosphere) larva. Regeneration is common.

Most annelids are marine. Many burrow or crawl upon the ocean floor especially **near** the shore. e.g., *Nereis* (sandworm or clamworm) (Fig. 10.16). Many marine species build tubes in which they live, e.g., *Chaetopterus*. Some species have become more or less terrestrial although they usually live in damp places. Earthworms are common examples of this type (Fig 10.17). Many annelids possess chitinous setae or chaetae embedded in sacs or in **parapodia** in the body wall and help in locomotion. All leeches are ectoparasites (Fig 10.17).

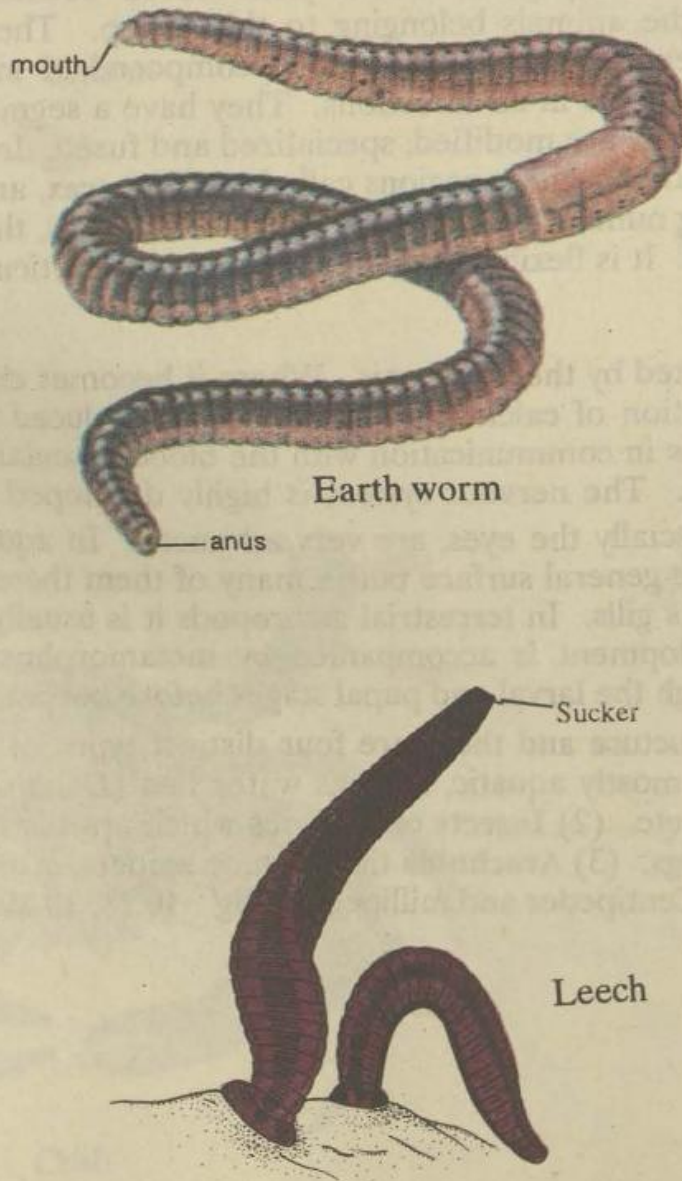


Fig.10.17 Earthworm and leech

Phylum Arthropoda- Animals with Jointed Legs

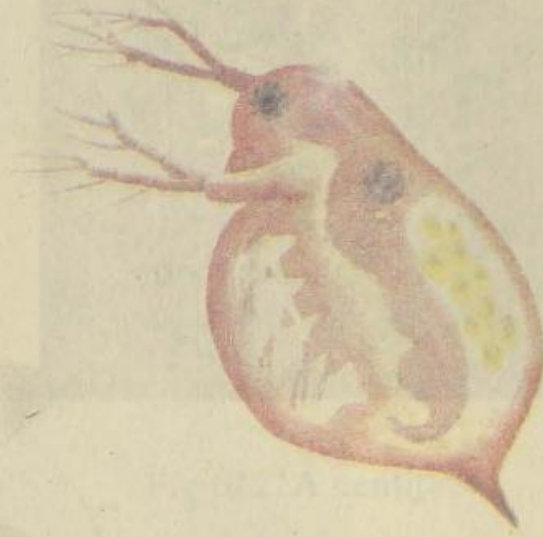
It seems that annelids and arthropods must have some common ancestors because both groups possess some common features such as presence of cuticle, appendages and segmented body. But, at the same time, the arthropods evolved several new advanced characters which made them the most successful phylum in animal kingdom. The success of a group is indicated from its diversity (number of species), abundance, and wide distribution. Consequently, arthropod species constitute about seventy five percent of the animal kingdom.

The very name of the phylum means joint-footed because this is a very important feature of the animals belonging to this group. They possess several pairs of limbs or appendages, each of which is composed of many parts hinged together to allow movements in all directions. They have a segmented body but in many cases their segments are modified, specialized and fused. In many arthropods the body is usually divided in three regions called **head**, **thorax**, and **abdomen**; each region having a varying number of segments. In all arthropods, the body is covered with a chitinous cuticle. It is flexible at many points to allow articulation.

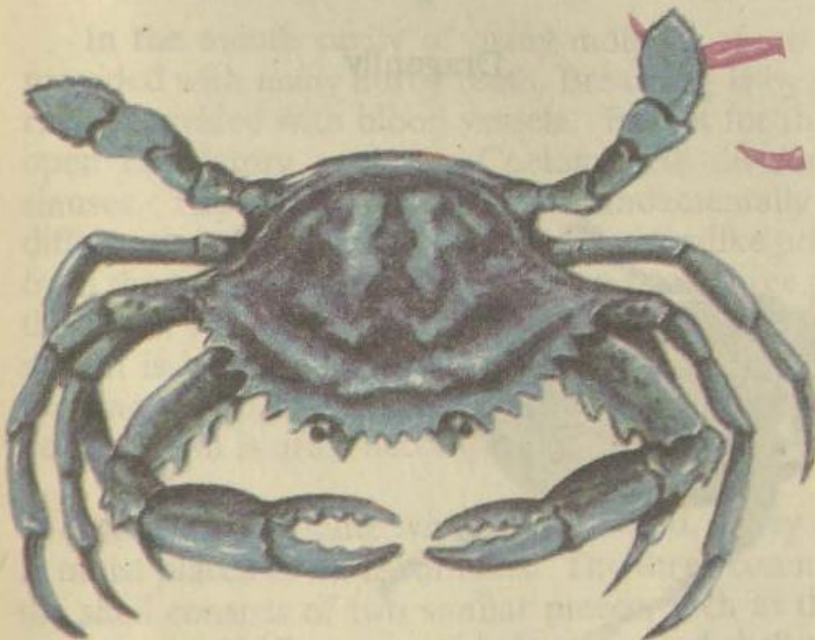
The cuticle is secreted by the epidermis. Where it becomes exceptionally hard, it is due to the deposition of calcium salts. Coelom is reduced and is known as **haemocoel**, because it is in communication with the blood vascular system which is therefore of open type. The nervous system is highly developed and centralized. Sensory receptors, especially the eyes, are very advanced. In aquatic arthropods, breathing is through the general surface but in many of them there are specialized breathing organs such as gills. In terrestrial arthropods it is usually by trachea. In most arthropods, development is accompanied by metamorphosis in which the embryo may pass through the larval and pupal stages before becoming adult. There is a great variety of structure and there are four distinct types of arthropods: (1) **Crustaceans** which are mostly aquatic, such as water flea (*Daphnia* and *Cyclops*), prawns, lobsters, crabs, etc. (2) **Insects** of all types which are distinguished by the presence of 3 pairs of legs. (3) **Arachnids** that include spiders, scorpions, ticks and mites. (4) **Myriapods**: Centipedes and millipedes (Fig 10.18, 10.19, 10.20, 10.21).



Prawn



Daphnia



Crab



Cyclops

Fig.10.18 Various kinds of crustaceans.



Privet hawk moth



Dragonfly



Stag beetle

Fig.10.19 Various kinds of Insects.



Fig.10.20 Scorpion.



Fig.10.21A centipede

Phylum Mollusca

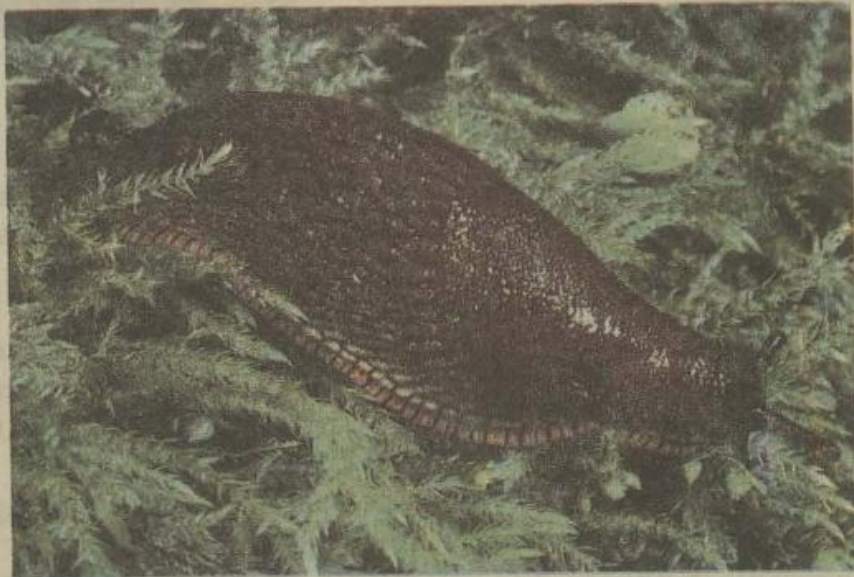
Molluscs are also bilaterally symmetrical, triploblastic and coelomate animals. They have an unsegmented body which is soft and divisible into a **head**, a ventral muscular **foot** and a dorsal **visceral region** containing most of the internal organs. The whole animal is covered in an envelope of glandular epithelial tissue called the **mantle**, which in many cases secretes a calcareous shell. In some cases the shell may be internal or even absent. The body is highly organized with complex digestive, respiratory, circulatory, excretory, nervous and reproductive systems.

In the mouth cavity of many molluscs there is a rasping tongue- like **radula** provided with many horny teeth. Breathing is by means of gills or mantle which is richly provided with blood vessels. Except for the group cephalopoda, there is an open circulatory system. Coelom gets divided into haemocoelic channels or sinuses. The excretory organs are fundamentally paired tubules; the nephridia are differentiated into a tubular and a bladder-like portion. Nervous system is different from the basic annelid plan and consists of three pairs of inter-connected ganglia in the head, foot and visceral mass. In some molluscs, such as squids, the nervous system is highly developed and there is a collection of ganglia in the head region forming a ganglionic mass. Sexes may be separate (unio) or united (helix) and development is often accompanied by the trochophore larva.

Mollusca are quite widely distributed. They may be fresh water, marine, living in moist places or on mountains. The three common types are: (1) **bivalves** in which the shell consists of two similar pieces, such as the fresh water or sea mussels; (2) **gastropods**, which are provided with coiled shell such as snails; and (3) **cephalopods** which are the most highly developed, such as squids, octopuses, etc. (Fig 10.22 and 10.23).



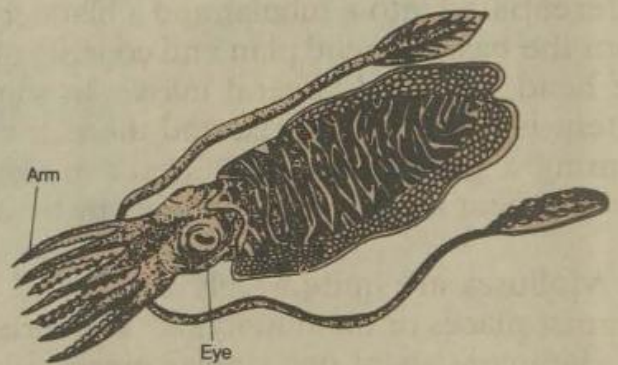
Fig.10.22 A Snail.



Slug



Cockle

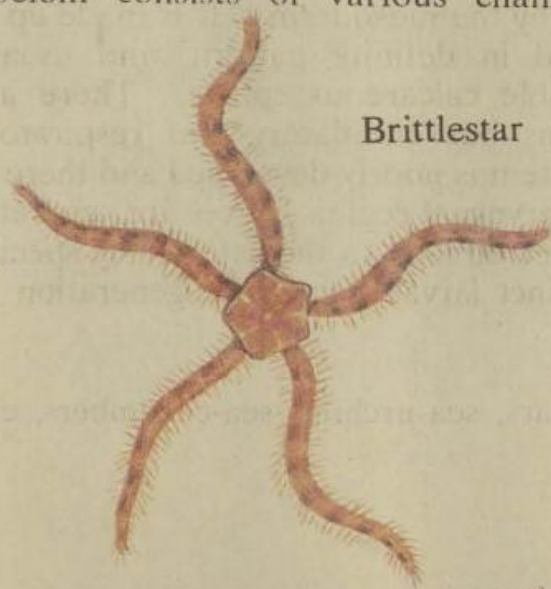


Cuttle fish

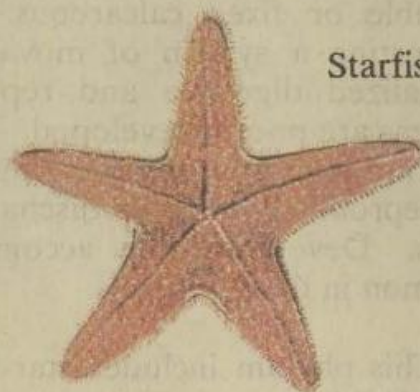
Fig.10.23 Various kinds of Molluscs

Phylum Echinodermata-Spiny-Skinned Animals

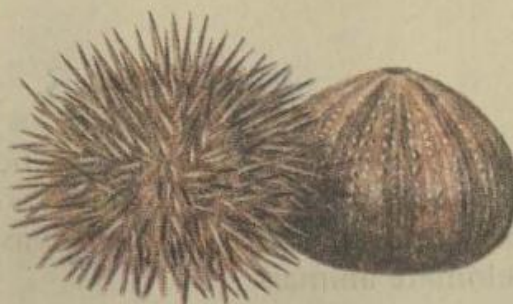
Echinodermata are exclusively marine. They are radially symmetrical animals. There is no head and no segmentation of the body. They are coelomate but the coelom consists of various channels and spaces, one of which forms the



Brittlestar



Starfish



Sea urchin (spines removed from one side)



Sea cucumber

Fig 10.24 Various kinds of Echinoderms

characteristic water vascular system consisting of system of channels for the circulation of water which enters through a sieve-like plate called **madreporite**. The body may be shaped like a disc or biscuit, or it may be star-shaped and in some cases elongated. The body is covered by a delicate epidermis under which there is a firm mesodermal exoskeleton which may also be considered as endoskeleton (because it is below the epidermis and formed by the mesoderm). It is made up of movable or fixed calcareous plates arranged in definite pattern, and usually supporting a system of movable or immovable calcareous spines. There are specialized digestive and reproductive organs but circulatory and respiratory systems are poorly developed. The nervous system is poorly developed and there is no brain but there is nerve ring around the pharyngeal region. Sexes are separate, the reproductive organs discharge their gametes directly to the exterior by special ducts. Development is accompanied by distinct larval stages. Regeneration is common in these animals.

This phylum includes star-fishes, brittle-stars, sea-urchins, sea-cucumbers, etc (Fig. 10.24).

QUESTIONS

1. What is the highest and the lowest group in classification ? What is a species?
2. Distinguish between diploblastic and triploblastic animals, and between acoelomate and coelomate animals.
3. There are two phyla that are predominantly marine and one phylum exclusively marine ? Name them. Which of them is the most highly evolved and how ?
4. What are the following ? Describe their functions :

(a) Mesogloea	(f) Coelom
(b) Nematocyst	(g) Pseudopodia
(c) Tube feet	(h) Water vascular system
(d) Trachea	(i) Canal system (sponges)
(e) Contractile vacuole	(j) Exoskeleton.
5. Classify the following animals and give their habitat.

(a) Plasmodium	(f) Lobster
(b) Mosquito	(g) Taenia solium
(c) Sea Cucumber	(h) Star fish
(d) Sycon	(i) Snail
(e) Scorpion	(j) Corals

6. Explain the following terms in detail.

- | | |
|--------------------------------|-----------------------------------|
| (a) Triploblastic organisms | (f) Bilateral and Radial symmetry |
| (b) Alternation of generations | (g) Binomial Nomenclature |
| (c) Polymorphosism | (h) Homoeostasis |
| (d) Parasites | (i) Conjugation |
| (e) Regeneration | |

7. Characterize and classify Arthropoda.

8. Describe characteristic features of Platyhelminthes. How do they differ from Nematodes ?

DIVERSITY IN FORM: ANIMALS PHYLUM CHORDATA

11

THE BEGINNING OF THE CHORDATES

The chordates include the vertebrates such as fishes, amphibians, reptiles, birds and mammals, and three other sub-phyla collectively known as **lower chordates** or **protochordates**, of which amphioxus is a typical example. All chordates show the following three fundamental characters, which may not persist throughout life (Fig. 11.1).

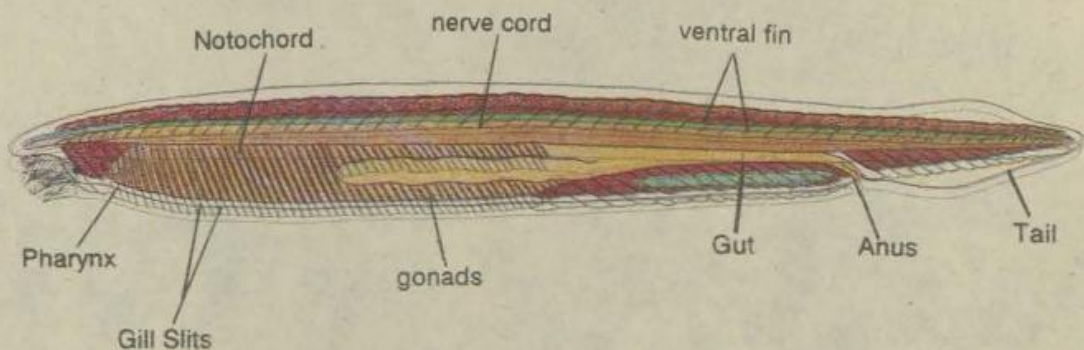


Fig 11.1 Amphioxus

(1) **Notochord**, which gives name to the phylum, is a stiff rod of special cells surrounded by connective tissue present in the mid-dorsal region and appears in the embryos of all chordates. In the lower chordates (protochordates) it is present as such throughout life but in the vertebrates it is replaced by a segmented cartilaginous or bony vertebral column or backbone.

(2) **Gill slits**, which are a set of openings in the pharyngeal region. In aquatic forms these function throughout life as gills or respiratory organs. In the vertebrates which possess lungs, they are transient, non-functional embryonic structures usually failing to open to the outside. They become modified to produce other structures such as the eustachian tube, etc.

(3) **Hollow, Dorsal, Central Nervous System.** Chordates possess a hollow, dorsal, fluid-filled nervous system above the notochord. It presents a marked contrast to the ventral ganglionated nerve chain which is characteristic of the invertebrates.

In addition to the above three exclusive characters, chordates also possess a tail which is a post-anal prolongation of the body containing no organs but extensions of muscles and nerve cord only. There is a well developed closed circulatory system consisting of a heart that pumps the blood. The sexes are always separate.

The chordates comprise about fifty thousand species, which are widely distributed. There is a great variety of structure and adaptations to various modes of life. Chordates are the only group which show the maximum range of size and include animals such as fish about an inch in length to whales as long as 100 feet and as heavy as 150 tons. On the other hand, high degree of specialization, differentiation, and complexity is evident even in the protochordates and goes on systematically from fishes to mammals as we shall see in the various classes.

Subphylum Vertebrata (Craniata)

Vertebrates are the largest and most advanced animals which can be easily distinguished by the presence of a vertebral column or backbone composed of bone or cartilage. They also have an internal living skeleton (endoskeleton) that extends to the head region in the form of skull. Most of the skull encloses the brain and is known as **cranium**, because of which the name craniata is also given to Vertebrata. The body is divided into three regions: head, containing brain and sense organs; trunk, containing the body cavity or coelom and all the viscera, and the tail which is the part behind the anus and is without viscera. Body wall consists of many layered epidermis and a dermis. The skin is usually covered with a protective covering of scales, bony plates, feathers or hair that form the exoskeleton. The animals typically have two pairs of limbs or fins which are jointed appendages. There is a closed blood vascular system with a well developed pumping heart that is ventral in position. Gill slits are present in the early developing stages in the higher vertebrates, but are permanent in the lower vertebrates. Sexes are always separate and only one pair of gonads (testes or ovaries) are present. Nervous system is highly developed with brain, spinal cord, cranial and spinal nerves.

There are eight different classes of Vertebrates, usually grouped into two super-classes, the Pisces which are all aquatic, mainly fishes; and Tetrapoda which are predominantly terrestrial. For convenience, we shall take Pisces also in the rank of a class.

Class Pisces: This group includes cartilaginous fishes such as dogfishes, skates and rays, and bony fishes that comprise most of the other fresh water or marine fishes.

The distinguishing features of class Pisces, in general, are the following:

- (1) The body is streamlined in such a way that the anterior end is smoothly rounded and reaches its maximum girth about one-third of the way from the front end, tapering gradually to the end of the tail. This shape offers minimum resistance to water, so very little energy is wasted.
- (2) Organs of breathing are the gills which are series of folds or pouches in the pharyngeal region and which persist throughout life. Water enters through the mouth and leaves through the gill slits.
- (3) Organ of locomotion is essentially the tail but paired and unpaired fins are also involved.
- (4) A dermal exoskeleton of scales is usually present but may be lost secondarily.
- (5) In the endoskeleton, notochord is partly or wholly replaced by bony or cartilaginous vertebrae.
- (6) There is well developed skull with upper and lower jaws, both of which normally bear teeth.
- (7) Middle ear is absent but internal ear is present. An air bladder or swim bladder is present in many bony fishes.

Jawless fishes are considered to be the most primitive and are surely the first of

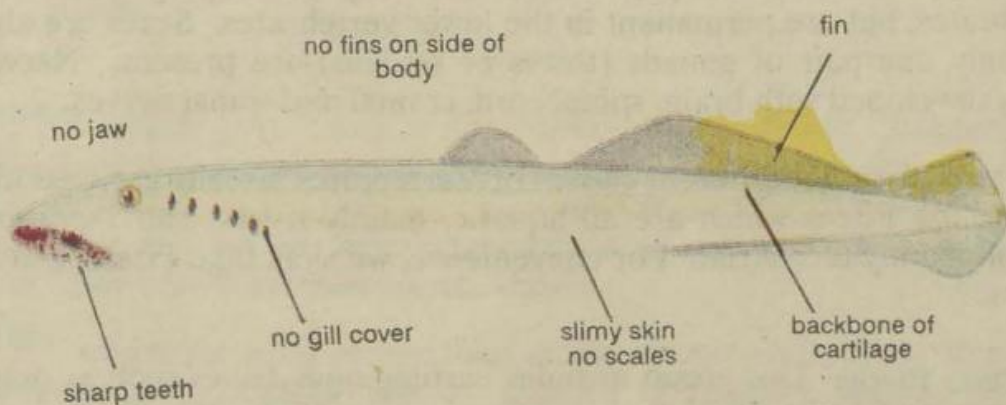


Fig. 11.2 Traits of Jawless Fish

the vertebrates. Their skeleton is composed of cartilage, and both jaws and appendages are absent. They are eel-shaped and possess a sucker-like mouth, and there is a persistent notochord (Fig. 11.2).

Cartilaginous fishes as the name shows, have cartilaginous skeleton e.g. *Scoliodon* (dogfish). The exoskeleton consists of dermal denticle-like microscopic scales. Their gills open directly to the exterior so that there is no lid-like operculum. Many of them retain eggs in the oviduct where development takes place. Sharks and some other fishes from this group reach very large size (Fig 11.3a)

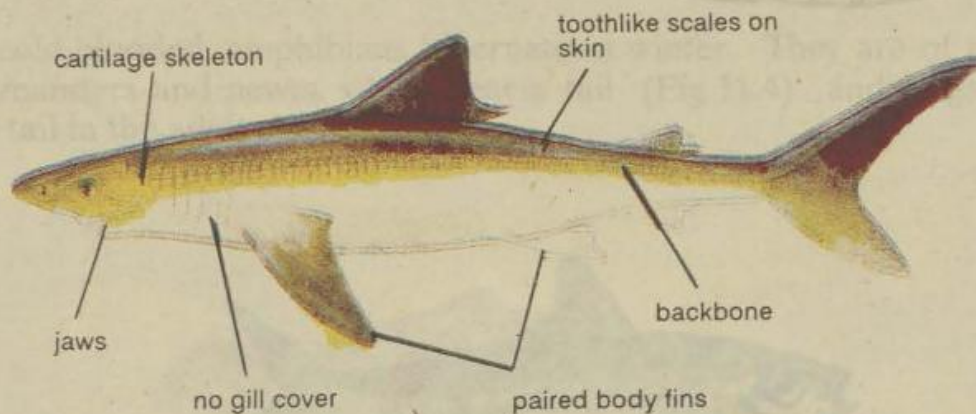


Fig. 11.3(a) Traits of Cartilaginous Fish

Bony fishes have the skeleton made chiefly of bones. The scales are of various types. The gills are covered by a bony flap, the operculum, so that there is a single exit of water on each side. In most of them there is a **swim bladder** or **air bladder** which is used in regulating buoyancy. There is a great variety of these fishes especially in fresh water as for example trout, pike, eel (Fig 11.3b)



Cod

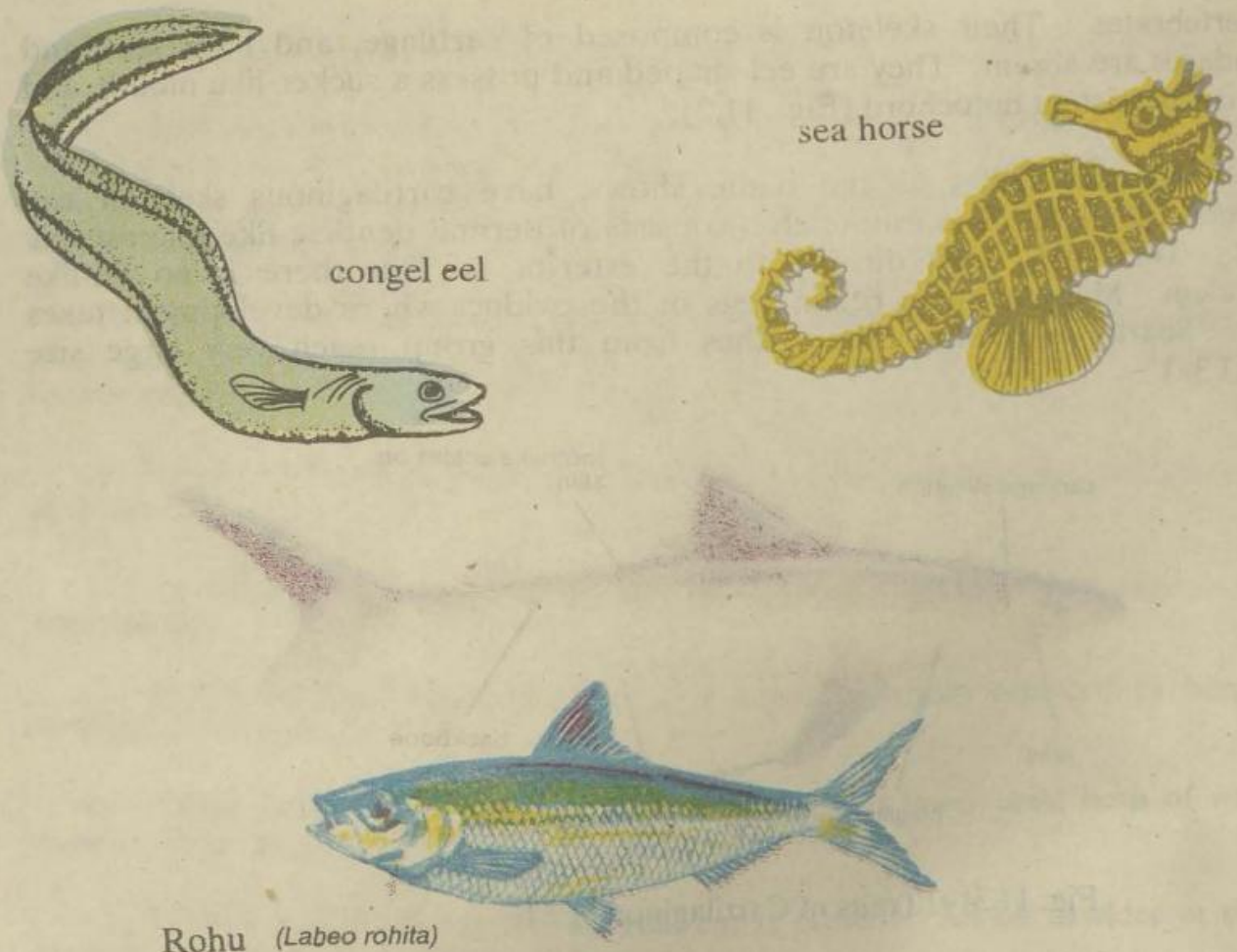


Fig. 11.3b Various kinds of bony fishes.

THE INVADERS OF THE LAND

Class Amphibia - Frogs and Toads, etc.

Fossil evidence indicates that the earliest terrestrial vertebrates were primitive amphibians. They arose from the extinct fish that possessed muscular lobe-like paired fins supported by bones. They lived in shallow water and moved from pool to pool with lobe-fins that helped them to crawl on land. The lobe-fins became the forerunners of the tetrapod limb. Moreover, like the present lungfishes, they possessed lung-like structures in addition to the gills, most probably as a supplementary means of obtaining oxygen. It is believed that these animals began to spend more time on land and gave rise to the primitive terrestrial forms, especially the early amphibians.

It is surprising that the present-day amphibians are the least numerous of the terrestrial vertebrates and least adapted for terrestrial mode of life. They are **cold blooded** or **poikilothermic**, i.e., their body temperature varies with that of the environment in which they live. In their adult condition, they possess characters

more like the higher terrestrial vertebrates but in their larval stage, they possess fish like characters. For example, they breathe by gills in the larval stage and by lungs in the adult, although in some, gills may be retained throughout life. When they began to live outside water for longer times the limbs strengthened to support the weight of the body on land and became modified to form five fingered or pentadactyle limb which were without claws. As their name indicates, they have a dual life, living both in water and on land. They have a smooth, moist, glandular and vascular skin which supplements the lungs in breathing. They have three chambered heart (in terms of atria and ventricle, otherwise it may be called five-chambered). Most amphibians have to go to water for reproduction and there is external fertilization with a few exceptions.

Being cold-blooded, amphibians hibernate in winter. They are of two distinct types, salamanders and newts, which bear a tail (Fig 11.4) and frogs and toads which lose tail in the adult stage.



Salamander

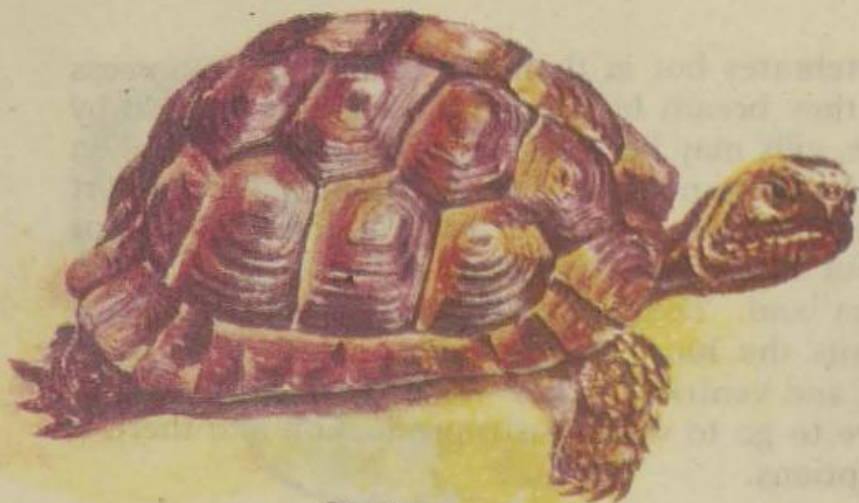


Newt

Fig. 11.4 Various kinds of Amphibians.

Class Reptilia - The Reptiles

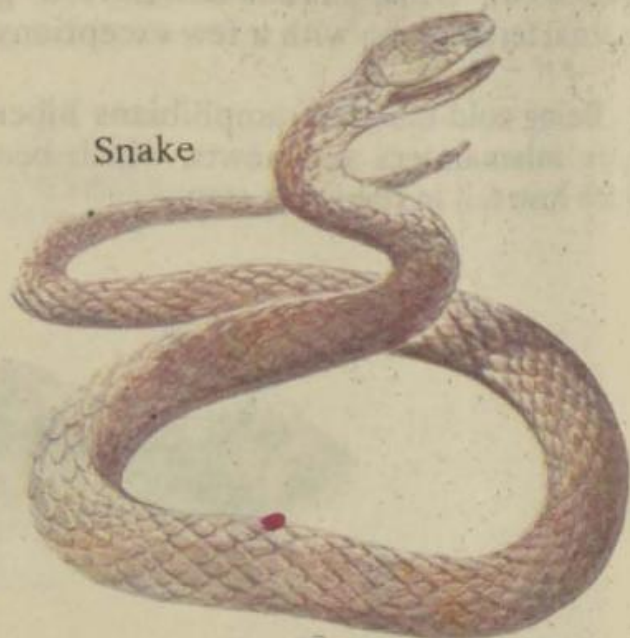
The first successful land vertebrates are in reality the reptiles, who unlike the amphibians, are in no way dependent upon water for their reproduction.



Tortoise



Lizard



Snake



Alligator

Fig. 11.5 Various kinds of reptiles.

There is no doubt that modern reptiles are found in both water (turtles) and on land (lizards) but they are predominantly terrestrial and some of them have adopted aquatic life secondarily (crocodiles, sea-snakes etc.) (Fig. 11.5). The complete adaptation to terrestrial conditions was made possible by important evolutionary changes in respiration, circulation, reproduction and development, etc.

The reptiles are also cold-blooded animals. They have a scaly skin which is normally dry and the scales are horny, epidermal structures modified in different ways. They are essentially tetrapods with pentadactyle, clawed limbs but great modifications have occurred in this respect. Lung-breathing is much more efficient than that of amphibians because of the increased surface area in the lungs. The heart is imperfectly four-chambered. There is an incompletely divided ventricle and thus separation of oxygenated and deoxygenated blood is not complete, although better than what is found in amphibians. The eggs are large, shelled, with much yolk and are laid on land. Fertilization is internal. Embryonic development takes place in a well protected suitable environment. During development, two distinct extra embryonic membranes develop, called the amnion and allantois, which have many functions including protection of embryo.

Reptiles, in present times, are represented by *Sphenodon*, tortoises, turtles, lizards, snakes and crocodiles, alligators, etc. They all belong to distinct groups and each group can be easily distinguished from the others because of its typical features. Reptiles flourished and were dominant throughout the Mesozoic period which was a long era extending about 230,000,000 to 63,000,000 (Two hundred and



Fig. 11.6 Some extinct Reptiles (Dinosaurs)

thirty to sixty three million) years ago in the geological time scale. During these times they were represented by some giant species commonly known as dinosaurs, whose fossils have been found in the rocks in different parts of the world (Fig. 11.6).

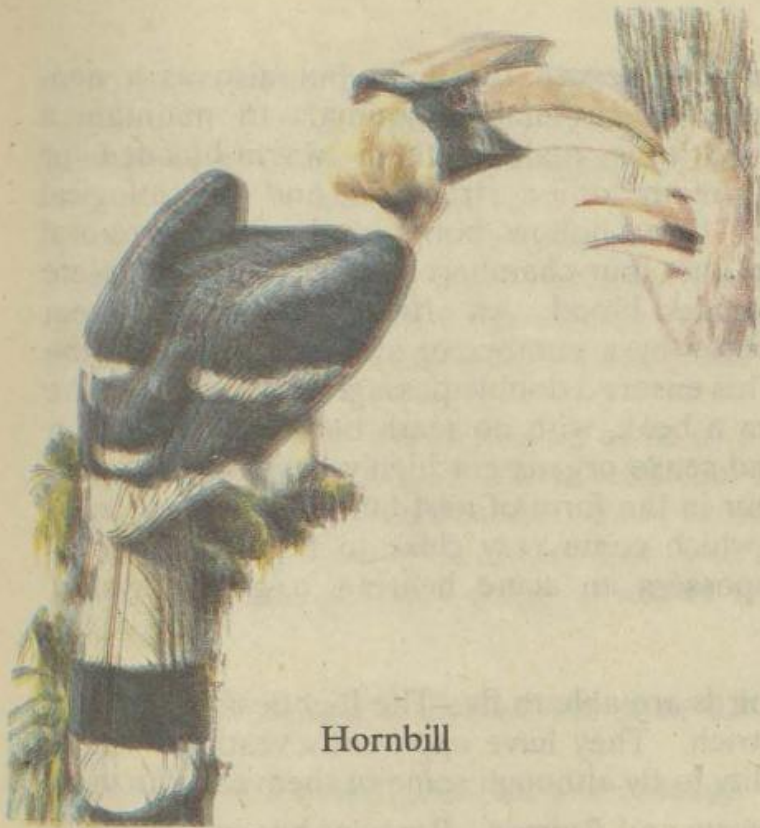
THE FEATHERED BIPEDS

Class Aves - The birds

There seems to be little doubt that birds evolved from the ancient reptiles. There are still some marked resemblances between the two groups: general features of the skull especially having one **occipital condyle**, the scales on the hindlimbs of birds, shelled eggs and embryonic development, are all similar. In the transition of birds from reptiles, the most important feature was the modification of forelimbs into wings and the development of feathers which must be connected with the efforts on the part of those reptiles that used to have long leaps and then acquired the adaptation to flight. Unfortunately many fossils of the transitional stages have not yet been found. However, the important discovery of the imprint of *Archaeopteryx* in 1861, which lies in the British museum, and another specimen found in 1877 called *Archaeornix*, which lies in the Berlin museum, provided ample evidence of transition. The former which may be called lizard-tailed bird was about the size of a crow. It had a long tail on both sides of which feathers were present. It had elongated jaws in the form of a beak having teeth in them and claws were present on the wings. All such features point to the transitional changes. (Fig. 11.7).



Archaeopteryx



Hornbill



penguin



Cassowary



Ostrich

Fig. 11.7 Various kinds of birds including a fossil bird Archaeopteryx

The development of feathers not only served for flight but also as a non-conducting layer for heat conservation which enabled animals to maintain a constant and high body temperature thus making them **warm-blooded** or **homoiothermic**. Flight necessitated many other structural and physiological changes such as the development of light, hollow bones and strong pectoral muscles. Other changes resulted in the four-chambered heart with complete separation of oxygenated and deoxygenated blood. An efficient breathing system evolved, consisting of lungs supplemented by a number of **air sacs** occupying the spaces between the internal organs. This ensured double passage of air through the lungs. The jaws are modified to form a beak, with no teeth but provided with a horny sheath. The nervous system and sense organs got highly developed so that birds show a highly organized behaviour in the form of nest-building, protection of the young, courtship, and migration which come very close to the behaviour of highest apes and man. Birds also possess an acute hearing, a good physical equilibrium and extremely keen vision.

Of course not all the present-day birds are able to fly. The flightless birds have a wide range in size from kiwi to ostrich. They have apparently vestigial wings, reduced feathers and have lost the ability to fly although some of them can run very fast. Other examples are *Rhea*, *Cassowary* and *Penguin*. *Penguins* became adapted to aquatic life and lost the power of flight. Unlike most other water-birds they swim by their fore-limbs which are modified into paddles or flippers. Some of their species live in the Antarctica (Fig. 11.7)

All other birds, which are called modern birds, present a great variety, are distributed in most parts of the world and show all the adaptations to flight.

The Hairy Animals

Class Mammalia - The Mammals

Of all the vertebrates, mammals have attained the most complete structural, physiological and developmental adaptations to terrestrial life, although some have become adapted to fresh water or sea and have become modified accordingly. Of all their characteristics that will be listed below, two features are most remarkable: the presence of hair serving for insulation and temperature regulation and mammary glands by which the females nurse their youngs. These animals are warm-blooded with a high rate of metabolism and great activity and they have become the dominant animals of the present times. They possess an external ear or pinna, the middle ear and the internal ear and their sense of hearing is well developed. The skin is provided with sweat glands for temperature regulation, and sebaceous glands which provide an oily secretion to the hair. Skull is provided with two occipital condyles and two jaws both of which have teeth set in sockets. Limbs are highly modified for different habits such as walking, running, climbing, swimming and flying etc., but have retained the pentadactyle pattern in majority of the cases. The heart is four-chambered and there is only the left aortic arch (while

in the birds there is only the right aortic arch) and the red blood cells are non-nucleated. Respiration takes place by lungs and respiratory movements are assisted by the ribs and **diaphragm**, which is a muscular partition separating the thoracic from the abdominal cavity. The brain is highly developed with complicated cerebrum and cerebellum. In most animals the urino-genital aperture is separated from the anus. In the male the testes usually descend in scrotal sacs which lie external to the abdomen. Fertilization is internal and development takes place in the uterus so that a young is born and nursed with milk after birth.

Mammals show a high degree of behaviour which has culminated in the most complex human behaviour. Their behaviour is based on learning and conditioning. Early mammals are supposed to have evolved from the early reptiles, on a line quite distinct from the line of the birds. Fossil record of horse, camel, elephant and other mammals provides ample evidence of the various changes that they have undergone.

Class Mammalia is divided into three sub-classes:

Sub-Class I. Prototheria (Monotremata)

The Egg-Laying Mammals

This group is represented in the present times by two genera, *Tachyglossus* (Echidna) which is commonly called the spiny ant-eater, and *Ornithorhynchus* commonly called the Duck-bill Platypus. Both are confined to Australia and some of the nearby islands. These animals are similar to each other but very distinct from other mammals, as they lay eggs but still suckle their young with milk. The mammalian features are presence of hair, diaphragm, the left aortic arch, relatively large brain with well developed cerebral hemispheres (cerebrum) and the presence



Duck-bill platypus



Spiny - anteater

Fig. 11.8 Two monotremes

of mammary glands in the female. The reptilian characteristics are that they lay eggs, have a common cloaca instead of separate anus and urinogenital aperture, and some characters of skeleton. But they also show many specializations. For example, there are no teeth in the adult. Platypus also possesses webbed feet, dorsal nostrils, long palate, soft fur and thick tail, all related to the aquatic mode of life. The spiny ant-eater is specialized for ant-eating habits, in having long snout, long tongue and large salivary glands. There are spines on the body while the feet are modified to make burrows and for digging the nests of the ants (Fig. 11.8).

Although prototherians seem to be intermediate between the reptiles and mammals, yet they cannot be considered ancestral mammals. It seems probable that while transition from the earliest reptiles to the mammals was going on, Australia and adjoining areas were separated from the main land mass and they became isolated and have continued with little change.

Sub-class II - Metatheria (Marsupials)

The Pouched Mammals

This group is represented by the kangaroos of Australia, Tasmanian wolf, opossum of North America and some other species found mainly in the Australian regions and some in America. In these animals, the female possesses an abdominal pouch or marsupium in which the mammary glands open. The young



Fig. 11.9 Kangaroo, a marsupial.

are born very early, in a rudimentary condition and are transferred to the pouch. Here they get nutrition and protection, and even after they are fully developed and able to move about, they retreat to the pouch for shelter. These animals do not have a true placenta so the viviparous condition is not similar to that in the placental mammals (Fig. 11.9).

The brain of marsupials shows some reptilian features. The cerebral hemispheres are rather small and olfactory bulbs large. The urinogenital aperture and anus are not very distinct especially in the female. These animals are generally burrowing in habit and are herbivorous. Their peculiar zoogeographical distribution is not clearly understood.

Subclass III - Eutheria (Placentalia)

The Placental Mammals

This is the largest group comprising all mammals except the monotremes and the marsupials. It seems probable that placental insectivores were the ancestral mammals of this group and as evolution proceeded, these animals began to flourish and developed into several divergent groups. At present they are widely distributed all over the earth, in different types of habitats such as land, water and even air. In due course of time several changes have occurred in them such as an increase in size, lengthening and specialization of limbs, reduction and specialization of teeth and enlargement and better development of brain, etc. These animals are called placental mammals because in the female a *placenta* is developed as an organ for nourishing the embryo, the development of which takes place in the uterus of the mother till birth of the young one.

This group is divided into about sixteen orders, some of the common ones are given below:

Insectivora, which includes moles and shrews.

Chiroptera, which includes flying mammals such as bat (Fig 11.10)

Rodentia, such as squirrels, rats, mice and beavers.

Cetacea, aquatic mammals such as whale, dolphins and porpoises (Fig 11.10)

Proboscidea, mammals with long trunk, such as elephant.

Carnivora such as dogs, cats, wolves, etc.

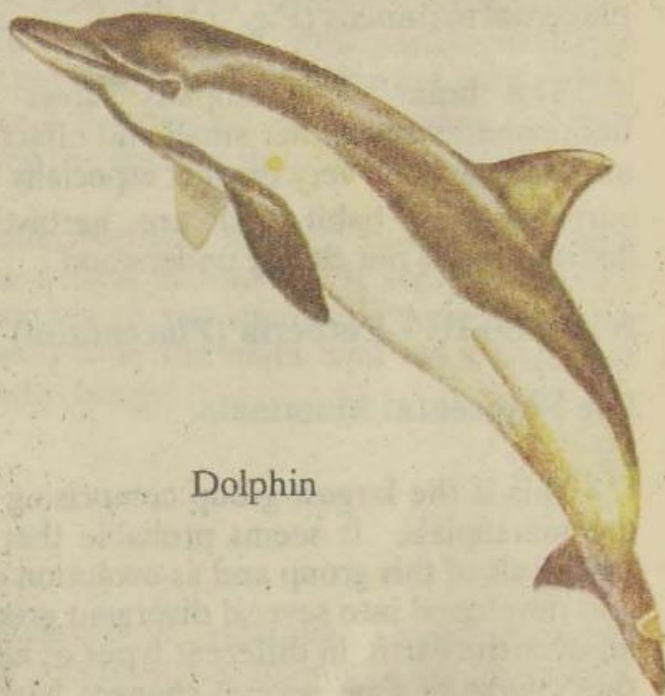
Perissodactyla, odd-toed hoofed mammals such as horses and zebras.

Artiodactyla, even-toed hoofed mammals such as deer and cattle.

Primates, such as lemurs, monkeys, apes and man.



Long eared bat



Dolphin



Tarsius



Dwarf lemur

Fig. 11.10 Some placental mammals.

QUESTIONS

1. What are the common characteristics of chordates?
2. What are the fundamental features of chordates?
3. Which group of vertebrates first invaded the land? Could they become purely terrestrial? If not which group successfully became terrestrial?
4. What are the common characteristics of mammals?
5. How are birds adapted to aerial mode of life?

6. a) Explain the following in detail.

Homiothermism, external fertilization, pentadactyle limbs, placenta and swim bladder.

- b) Differentiate between the following:

- i) Cartilage fish and bony fish.
- ii) Snake and lizard.
- iii) Flightless bird and flying bird.

- iv) Notochord and nerve Cord.

- v) Perissodactyla and Artiodactyla

7. Characterize Amphibia and Reptilia. Give examples.

DIVERSITY IN FUNCTION: PLANTS WATER RELATIONS; PHOTOSYNTHESIS

12

WATER AND SALT ABSORPTION

A plentiful supply of water throughout the plant body is apparently an essential prerequisite for the normal functioning of the vital processes. Air dried organs, such as seeds, accordingly show hardly any measurable metabolic phenomena. How the plant acquires the water so essential for its well being, and how it is able to maintain the optimal hydration of its tissues are important and fundamental problems in the physiology of metabolism.

Diffusion

If a perfume-filled bottle is opened in a room, its smell will be distributed throughout the available space in that room. Similarly, if a crystal of potassium permanganate (solute) is placed in water (solvent) it is dissolved and its molecules or ions move and are evenly distributed throughout the water (solvent). This movement of molecules or ions in a solvent from area of its high concentration to area of low concentration is called as **diffusion**.

In plants generally water vapours diffuse outwards and gases, mainly oxygen and carbon dioxide diffuse in both directions between the plant organs and the surrounding atmosphere. Diffusion is responsible for such processes as transpiration and exchange of gases during photosynthesis and respiration.

Osmosis

Osmosis is a phenomenon almost parallel to diffusion. The only difference is the presence of semi permeable membrane. The solvent (usually water) from the less concentrated solution flows into the solution of higher concentration through the separating membrane, till both the solutions attain equal solute concentration

i.e. become isotonic. The process by which movement of solvent molecules take place through a semi-permeable membrane from a region of low solute concentration to a region of higher concentration is known as **osmosis**. It is of great importance in the maintenance of cell turgor and also in vascular transport.

The osmotic process can be demonstrated by a very simple experiment. Tie a piece of cellophane paper over the wide end of thistle funnel. A strong sugar solution of sucrose is poured into the thistle funnel but it should not fill the entire funnel. The cellophane paper acts as semi-permeable membrane allowing water but not dissolved solutes, such as sucrose, to pass through. The cellophane paper end of the funnel is placed in a beaker of distilled water and the stem of the funnel is clamped with stand. The level of the sugar solution in the stem of funnel is marked. After sometime the level of the solution in the stem is noted. The new level is marked (Fig: 12.1).

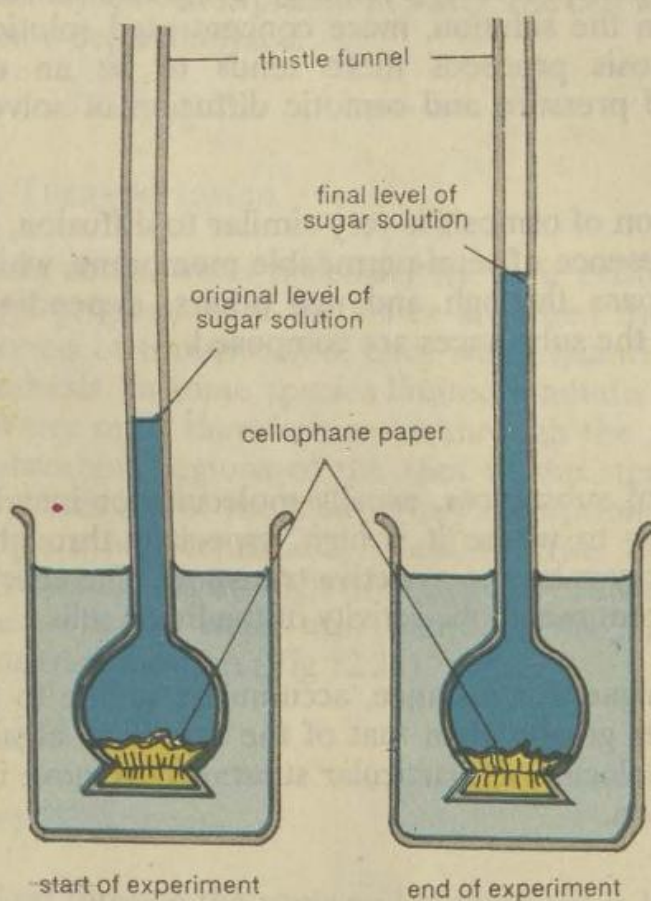


Fig. 12.1 Experiment to demonstrate Osmosis

As a result of the separation of solution from its solvent (usually water) in the demonstration of osmosis, water will move both in and out of the funnel. However, the rate of movement of water moving into the funnel will be higher than that of

water moving out. This is because the concentration of water in the beaker is higher than the concentration of water in the thistle funnel. Under these circumstances water will accumulate in the funnel, and consequently the column of water will rise in the stem of funnel. As water accumulates in the funnel, the sugar solution becomes more and more diluted, and the rate of water moving into the funnel slows down accordingly. If no other factors were involved, the amount of water moving into the funnel would always be greater than the amount moving out. However, as the column of water builds up in the stem of funnel, it exerts a pressure which causes a continually greater amount of water to move out of the funnel. Eventually, an equilibrium is reached where the forces controlling the movement of water into the funnel balance those controlling the movement of water out of the funnel.

In the above situation, the solution of higher concentration is said to have a higher osmotic concentration and to exert a higher osmotic pressure than the other solution. The osmotic pressure is directly proportional to the concentration of dissolved solutes in the solution, more concentrated solution has higher osmotic pressure. As osmosis proceeds there tends to be an equalizing of osmotic concentrations and pressure and osmotic diffusion of solvent molecules will not take place.

The phenomenon of osmosis is very similar to diffusion, the only distinguishing factor being the presence of semi-permeable membrane, which allows certain types of substances to pass through and not others, depending on the size of the molecules of which the substances are composed.

Active Transport

The transport of substances, usually molecules or ions from region where its concentration is low to where it is high, especially through a membrane by the expenditure of energy is known as **active transport**. The energy for active transport comes from a different metabolic activity of the living cells.

Many marine algae, for instance, accumulate iodine to a concentration more than a million times greater than that of the sea. Such algal cells therefore, have means of forcing molecules of particular substance to move in a direction opposite to the law of diffusion.

Imbibition

The process by which a substance takes up a liquid and, as a consequence swells in volume, but does not dissolve is known as **imbibition**. For example, when some pieces of gum or dry seeds are placed in water they absorb the water quickly and swell up considerably so that their volume is increased.

Imbibition which is usually reversible, is exhibited by many biological compounds, particularly by cell wall constituents, such as pectin, cellulose and lignin. The tough seed coat of dry seeds imbibe water and ruptures just prior to germination, allowing the enclosed embryo to grow. Cell walls of root hair also imbibe water from the soil.

Plasmolysis

The shrinkage of protoplasm due to exosmosis of water from the cell, is known as **plasmolysis**. Such a cell is said to be plasmolysed. The return of the cell to its original position is said to be **deplasmolysis** and such a cell is called **deplasmolysed**.

If a cell is placed in a concentrated solution of either sugar or salt the water contents of the cell will come out and the protoplasm will shrink. This cell is called **plasmolysed**. If the plasmolysed cell is placed in water, the cell will gain its original position and it will become deplasmolysed.

TRANSPORTATION

Concept and Need for Transportation

Most terrestrial plants obtain water necessary for their existence from the soil. An overwhelmingly large proportion of the water absorbed by the roots of land plants is lost in the process of transpiration. Only small quantities are utilized in growth and in photosynthesis. In some species limited amounts of water may also be lost by **guttation**. Water must therefore move through the intervening tissues and organs from the absorbing regions of the root to the stem and leaf tissues where it is utilized, or passes out of the plant. Thus absorption of water from the soil by the roots of a plant is a continual process, the rate of absorption being dependent on the rate of water loss through transpiration or its utilization in active metabolism. The process whereby water moves through the plants is termed the **conduction, transport or translocation** (Fig 12.2a).

1. Ascent of Sap

(Conduction of Water)

Water enters the plant through the roots and is given out in large quantities, by the leaf. So we are faced with the unavoidable question of how the water moves from the bottom to the top of plant traversing large vertical distances.

The general pathway that the water follows in its ascent has been clearly identified. This pathway can be traced by a simple experiment. Put a cut stem in water coloured with any harmless dye (preferably, cut the stem under the water to prevent air from entering the conducting elements of the xylem) and then trace the

path of the liquid into the leaves. You will find that the stain quite clearly delineates the conducting elements of the xylem. More recent experiments using radioactive isotopes placed in water given to the plant confirms that the water does indeed travel through the vessel elements (or tracheids) in the xylem (Fig. 12.2.b.c). The majority of evidences for example, ringing experiment and the use of radioactive materials however, indicate that minerals are also transported through xylem to most parts of the plants.

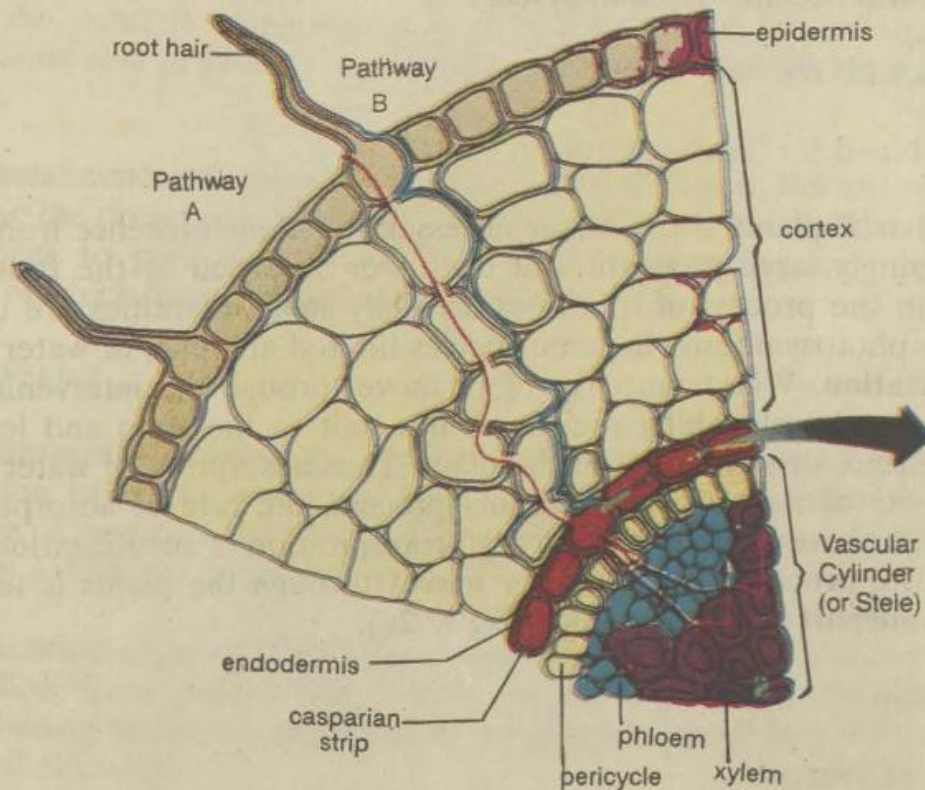


Fig.12.2(a) Diagrammatic cross section of a root, showing the pathways of uptake of water and minerals. Along pathway A, water moves by osmosis and salts by active transport across the cell membranes of living cells. Along pathway B, the water flows through the cell walls and along their surfaces, and the solutes flow with the water or move by diffusion.

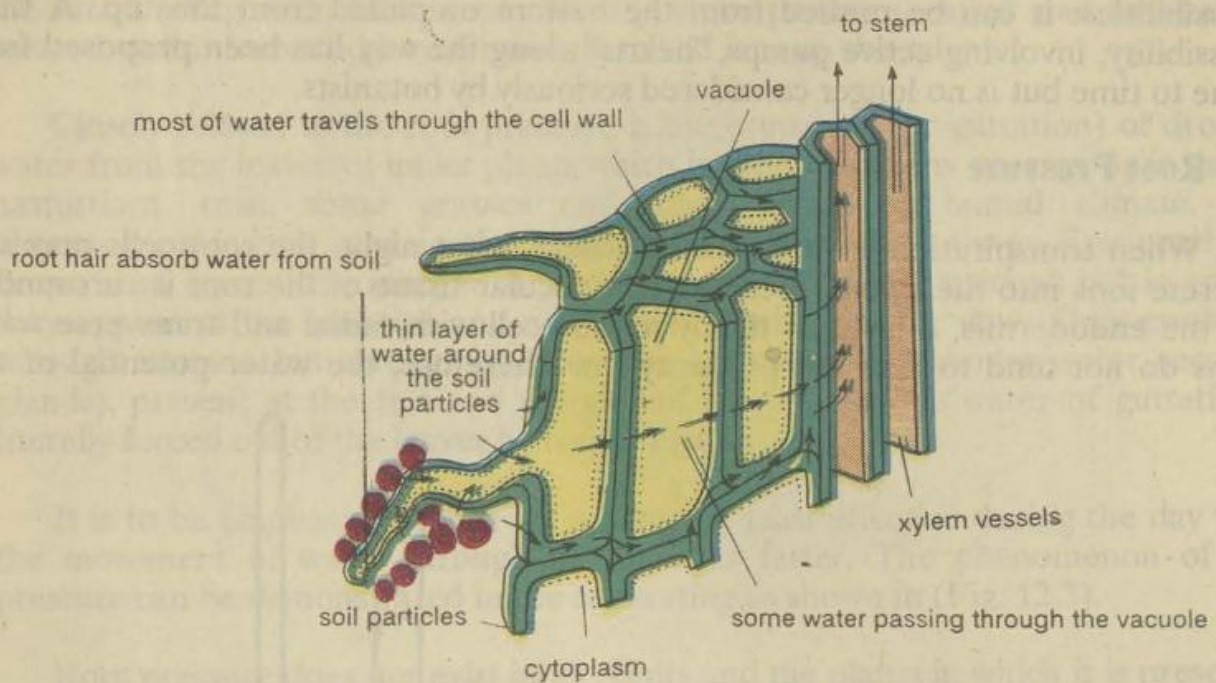


Fig.12.2b Diagram to show the passage of water from soil to xylem vessels in a root.

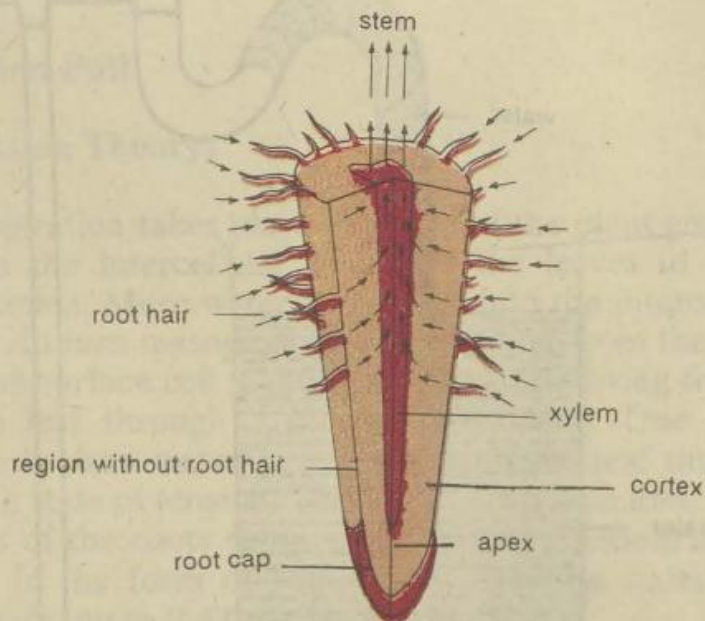


Fig.12.2c Diagrammatic section of root to show passage of water from the soil.

So we know the path that water takes but how does it move? Logic suggests two possibilities: it can be pushed from the bottom or pulled from the top. A third possibility, involving active pumps, "hearts" along the way has been proposed from time to time but is no longer considered seriously by botanists.

(a) Root Pressure

When transpiration is very slow or absent, as at night, the root cells may still secrete ions into the xylem. Because the vascular tissue of the root is surrounded by the endodermis, a layer of tightly packed cell with radial and transverse walls. Ions do not tend to leak out of the xylem. Therefore, the water potential of the

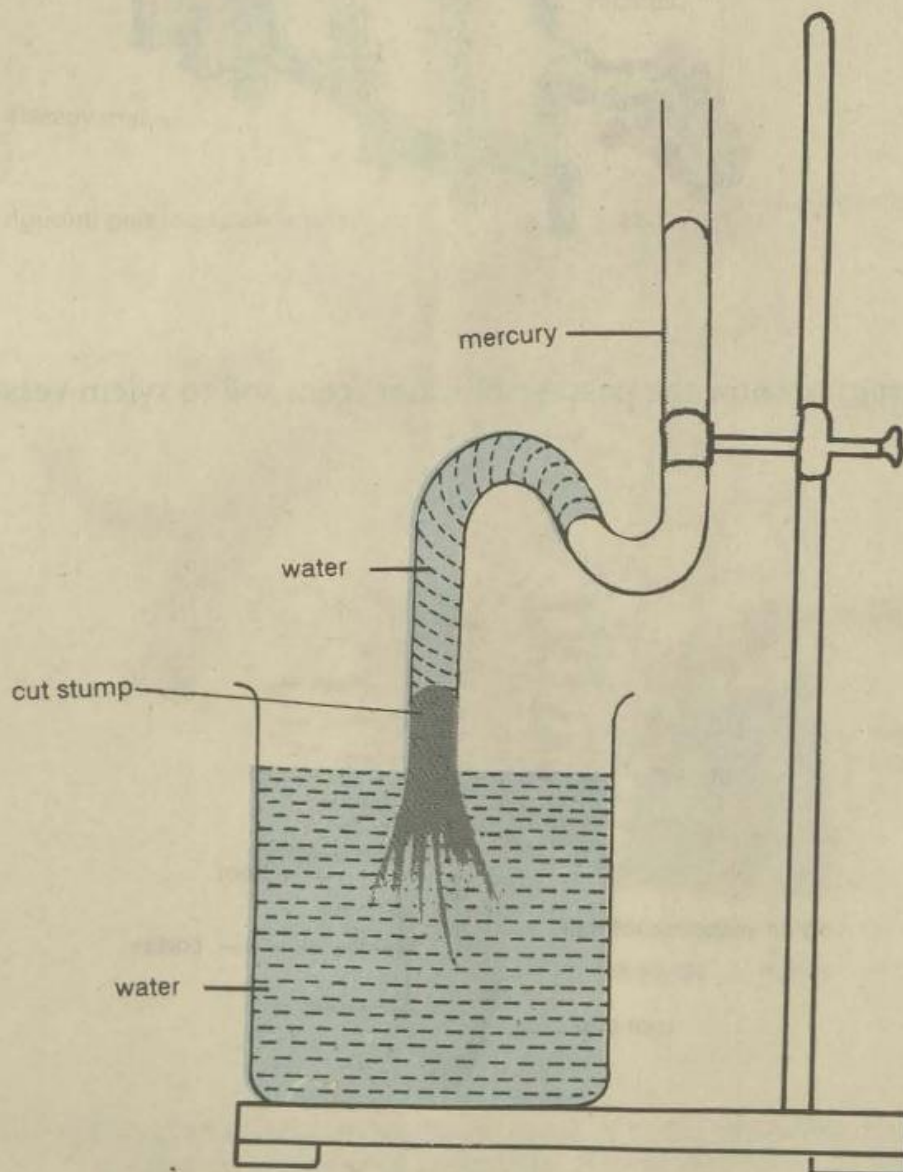


Fig. 12.3 Demonstration of root pressure in the cut stump of a plant. Uptake of water by the plant roots causes the mercury to rise in the column. The pressure of 3 to 5 bars have been demonstrated by this method.

xylem becomes more negative, and water moves into the xylem by osmosis through the surrounding cells. In this manner a positive pressure, called **root pressure**, is created, and it forces both water and dissolved ions up the xylem.

Closely related to the root pressure is the exudation (or guttation) of drops of water from the leaves of intact plants which is shown by many species, as in garden nasturtium, rose, some grasses and many plants of humid climate. This phenomenon is best seen in the early morning in summer times. Frequently the drops form around the margin of the leaf (as in broad leaf species) but in grasses they appear at the leaf tips and may often be mistaken for dew. They exude not through stomata but through special openings called hydathodes (water secreting glands), present at the tips and margins of the leaves. The water of guttation is literally forced out of the leaves by root pressure.

It is to be emphasized that root pressure is least effective during the day when the movement of water through the plant is faster. The phenomenon of root pressure can be demonstrated in the caborating as shown in (Fig. 12.3).

Root pressure does not exist in all plants and the plants in which it is present, is not sufficient to move water to the top of a tall tree. Moreover, the simple experiment just cited involving the cut stem rules out root pressure as a crucial factor. So we are left with the hypothesis that water is pulled up through the plant body.

(b) Transpiration Pull

(Cohesion-Tension Theory)

When transpiration takes place in leaves of the plant growing in soil, the water evaporate from the intercellular spaces of the leaves to the outer atmosphere through the stomata. More water is released into the intercellular spaces from the mesophyll cells. In turn mesophyll cells draw water from the xylem of the leaf. The water lost by the surface cell is replaced by water moving from cells deeper in the interior of the leaf through a process of osmosis. Due to this, the leaf cells ultimately have to draw water from the vein of the leaf thus putting water in the xylem tissue in a state of tension. This tension is transmitted downwards to water in xylem elements of the roots through the xylem of petiole and stem. The water is pulled upward in the form of continuous unbroken water column to reach the transpiring surface, up to the top of plant (Fig.12.4 a).

Imagine, if you have, a long hollow glass tube, one end of which is submerged in a beaker of water. The tube is filled with water so that there is an unbroken connection between the water in the beaker and in the tube. If a thoroughly soaked sponge is placed at the other end of the tube so that a connection is made between

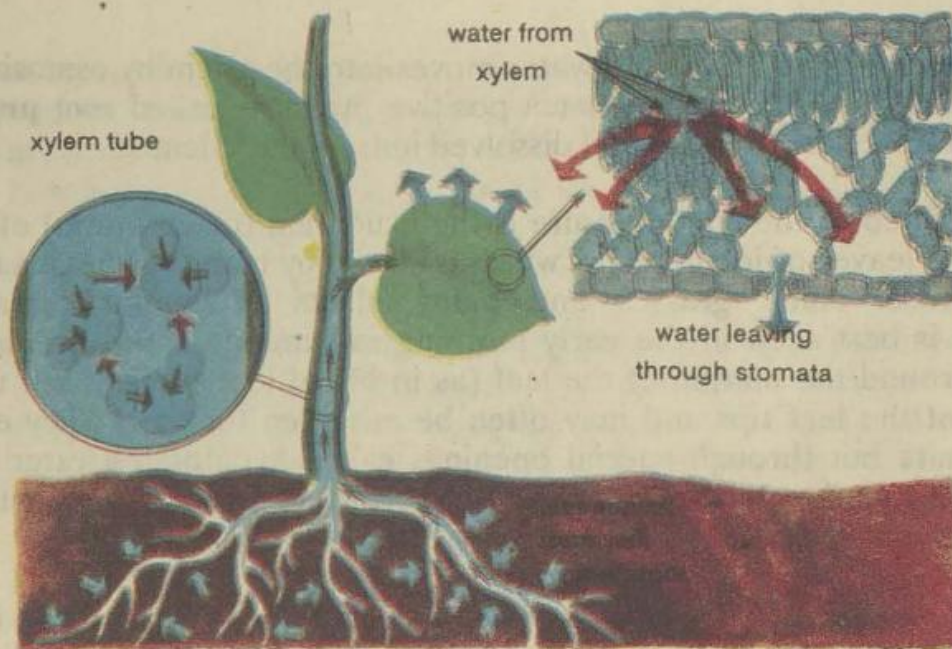


Fig 12.4a Movement of water up the stems of trees is explained by the cohesion-tension theory. Cohesion among water molecules (inset) gives water increased density. Transpiration from leaves exerts a "pull" on this dense water in xylem vessels.

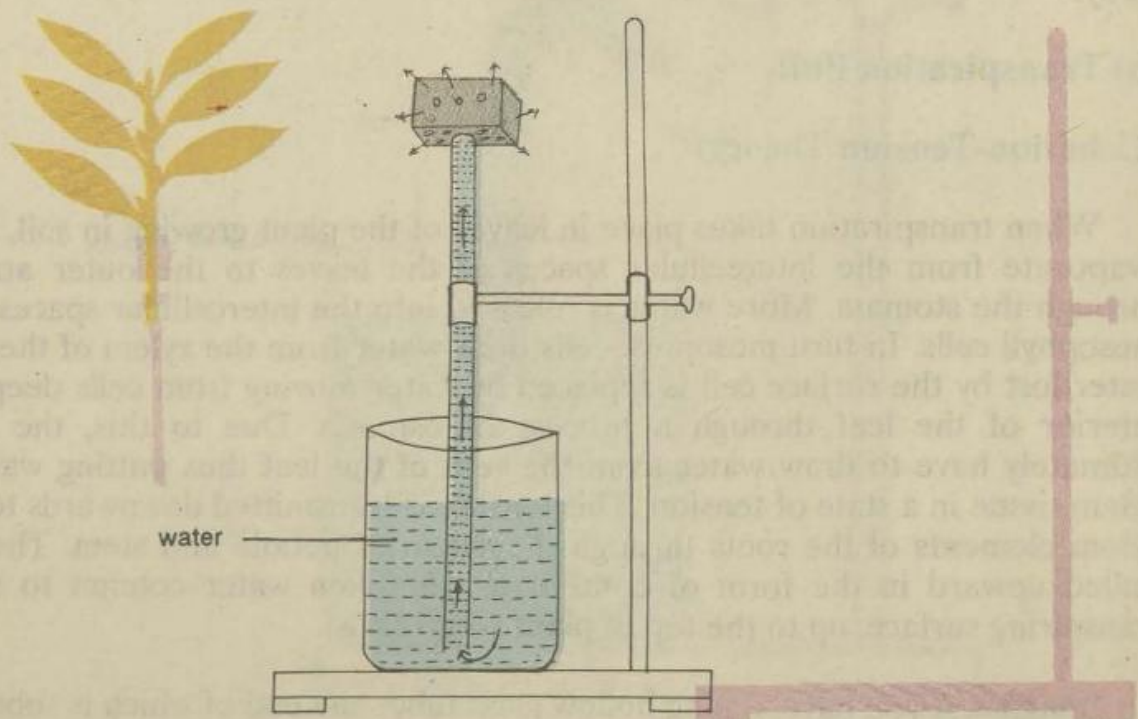


Fig. 12.4b A physical system for demonstrating the cohesion - tension theory. Water evaporating off the surface of the sponge will be replaced by the water in the glass.

the water held by the sponge and the water in the tube, an unbroken column of water can be "pulled up" from the beaker (Fig. 12.4 b).

The phenomenon of transpiration pull can also be demonstrated with the experiment, i.e., if at the top of a glass tube with continuous water column a fresh leafy twig is fixed and its water is subjected to transpiration, the water column is put under tension and it is replaced by water in the tube which, in turn is replaced by coloured water from the beaker. How is it possible to pull a column of water up a tube without having the column break? Why does not the column of water when under tension (being pulled), pull away from the glass wall of the tube? The water molecules cohere to each other and, at the same time, adhere to the glass wall of the tube. Therefore, the water column will not break until its cohesive and adhesive strength is overcome by gravitational pull on the column.

Assuming that we are convinced that water—due to its cohesive and adhesive properties and to the anatomy of the xylem tissue—can be pulled up in an unbroken chain through the plant, our next question should be "can the tensile strength of water support the column of water that would be necessary to reach the tops of our highest trees"? The answer to this question is yes. Measurements of the tensile strength of water have exceeded 300 atm. To raise water to the top of a 400 feet tree would require a difference in pressure of about 13 atm, between the top and bottom. In the above statement, we neglected to mention the friction of water would encounter moving through the xylem tissue. Although this is considerable, it is obvious that the tensile strength of water is sufficient to overcome the frictional and gravitational forces encountered in its vertical rise in plant.

The Cohesion-tension theory was originally proposed by Dixon and Jolly (1894) and greatly supported and elaborated by Dixon (1914, 1924). This theory is the most plausible explanation today of the translocation of water in plants. Root pressure is capable of moving water upward in a plant, but not to the required quantity and to height of the most plants. Probably the strongest argument for the cohesion-tension theory is that it is the only theory that can account for the quantity and the rate of water movement in a vigorously transpiring plant.

Conduction of Food Material Through Phloem

Much valuable information on movement of substances in the phloem has come from studies utilizing aphids, small insects that suck the juices of plants. Most species of aphids are phloem feeders. When these aphids insert their modified mouth parts, or stylets, into a stem or leaf, they extend them until the tips of the stylets puncture a conducting sieve tube. The turgor pressure of the sieve tube then forces the sieve tube sap through the aphids digestive tract and out its posterior end as droplets of "honey dew". If feeding aphids are anesthetized and severed from the stylets, exudation often continues from the cut stylets for many hours. The sieve-tube exudate can be collected from the cut ends of the stylets with a micropipette

and analyzed. Analysis of exudates obtained in this manner reveal sieve-tube sap to contain 10 to 25 percent dry matter, 90 percent or more of which is sugar, mainly sucrose in most plants. Low concentration (less than 1 percent) of amino acids and other nitrogen-containing substances are also present. The use of radioactive tracers has also provided information on phloem transport.

The Pressure Flow Mechanism

The first person to give serious attention to Hartig's ideas on assimilate movement in the phloem was E. Munch, who in 1927 proposed the pressure flow hypothesis. Since its postulation, this hypothesis has been modified but its major features remain unchanged. According to the pressure-flow hypothesis, assimilates move through the sieve tubes along concentration gradients between the sources of assimilates and the sites of utilization, or sinks, of those assimilates. Sources are places where food substances are available for transport, such as photosynthesizing leaves or storage regions. Examples of sinks are growing and differentiating tissue regions and storage regions.

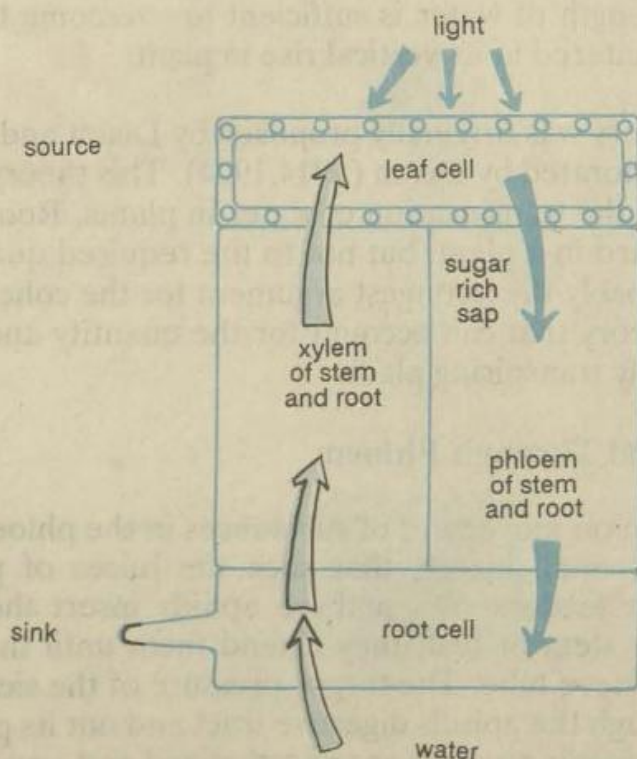


Fig. 12.5 A diagram to illustrate the mechanism of assimilate movement according to pressure flow hypothesis.

The pressure flow mechanism can be explained if we take a photosynthesizing leaf or mesophyll cells as a source and root cells as a sink. As a result of photosynthesis, the mesophyll cells in the leaf contain sugar rich sap and cause an increase in the osmotic concentrations of these cells. The mesophyll cells draw water from the xylem of the leaf due to higher osmotic pressure of their sap, so that their turgor pressure is increased and forcing the sap through the phloem sieve tubes down to the roots, under the gradient of turgor pressure. In the living cells of stem and the roots the organic solutes are either consumed or converted into soluble form.

The pressure flow mechanism not only depends on the turgor pressure, but also on the difference of osmotic pressure gradient along the direction of flow between the sources and sinks.

The roots also absorb water in response to osmotic gradients. This water is carried up to the leaves by a combination of root pressure and transpiration pull through xylem of root and stem. This completes the circulation of nutrients in the plant. At present, the pressure flow mechanism is the most widely accepted explanation for the movement of substance in the phloem (Fig. 12.5).

TRANSPIRATION

The loss of water by evaporation from plant surface is called **transpiration**. Over 90 % of water escapes through the open stomata, while about 5 % is lost directly from the epidermal cells. It has been shown that although the combined area of stomatal pores is an average only 1-2 % of the total leaf area. The amount of transpiration they allow is 90 % of the transpiration that occurs from a water surface of the same area as the leaf.

Transpiration rates are greatest when the leaf cells are fully turgid and when the relative humidity in the atmosphere is low. Water forms a film around the mesophyll cells and evaporates into the substomatal chamber from where it diffuses into the air. The degree of opening of the stomata (stomatal resistance) is of prime importance in governing the rate of water loss. In dry conditions, transpiration can cause wilting and so the plants develop several features to minimize the water loss due to evaporation.

Cuticular and Stomatal Transpiration

Leaves are covered by a cuticle that makes the surface of the leaf largely impervious both to water and carbon dioxide. A small fraction of the water transpired by plants is lost through this protective outer coating and another small fraction is lost through the lenticels in bark. The largest amount of water transpired by a higher plant is lost through the stomata.

Stomata are small openings in the epidermis that are opened and closed by changes in turgor of the two surrounding guard cells. Stomata are also found on young stems, but they are far more abundant on leaves. The number of stomata may be quite large, for example, there are 12,000 stomata per square centimeter of

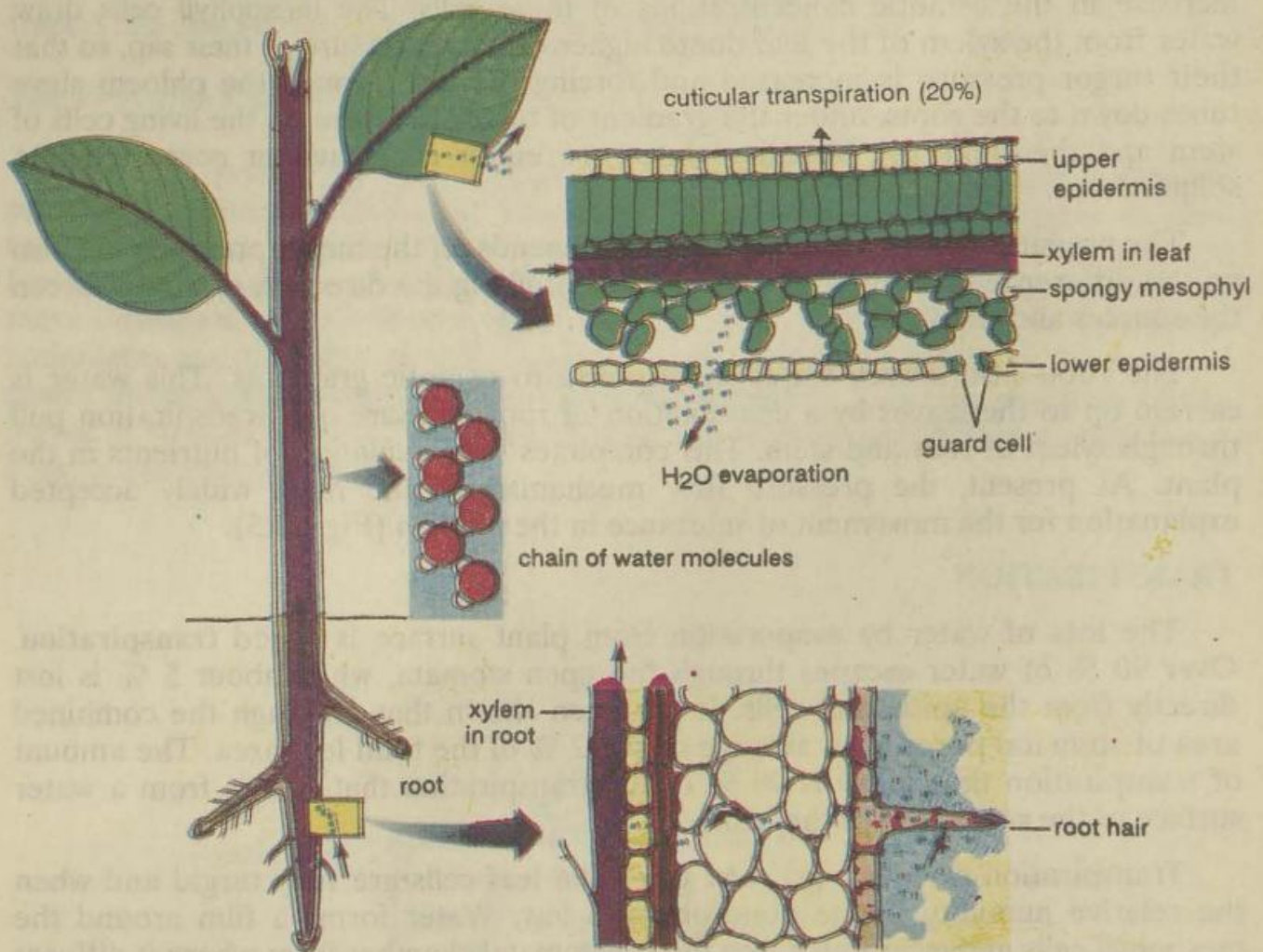


Fig 12.6a Transpiration: Key to upward water movement in plants. When the air surrounding a plant is not saturated with water vapour, water will evaporate from the leaves. Water is taken up through the roots of the plant by osmosis and moves up the stem to the leaves, where it evaporates into the intercellular spaces of the leaf. Then water vapour exits the leaf through the stomata.

leaf surface in tobacco leaves. The stomata lead into a honeycomb of air spaces within the leaf that surround the thin walled mesophyll cells. The air in these spaces, which makes up 15 to 40 percent of the total volume of the leaf, is saturated with water vapours that have evaporated from the damp surface of the mesophyll cells.

Stomatal transpiration involves two processes: (1) evaporation of water from cell wall surfaces bordering the intercellular spaces, or air spaces, of the mesophyll tissue, and (2) diffusion of the water from the intercellular spaces into the atmosphere by way of the stomata (Fig. 12.6 a,b).

Closing of stomata not only prevents the loss of water vapours from the leaf but also, of course, prevents the entry of carbon dioxide into the leaf. A certain amount of carbon dioxide, however, is produced by the plant during respiration, and as long as light is available this carbon dioxide can be used to sustain a very low level of photosynthesis even when the stomata are closed (Fig. 12.6b).

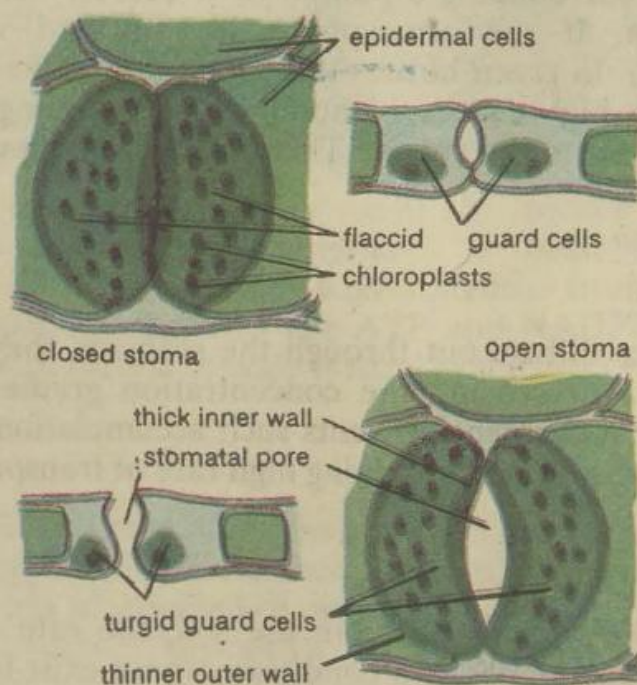


Fig. 12.6 b Mechanism of stomatal movements.

Factors Affecting Transpiration

Environmental conditions may vary considerably even over short periods of time. Changes in transpiration rates result from an effect of the environment upon the vapour pressure of water or upon the stomatal openings.

1. Temperature

The important factor which affects the transpiration is temperature. The rate of water evaporation doubles for every temperature rise of about 10°C. However,

because evaporation cools the leaf surface, its temperature does not rise as rapidly as that of the surrounding air. If the temperature exceeds 30 to 45°C stomata close.

2. Light

Light occupies a prominent position among the factors influencing transpiration, since it has a dominating effect on stomatal movement. The stomata of a plant exposed to light are opened, allowing transpiration to proceed. In the dark, stomata are closed and transpiration essentially ceases. The effects of other environmental factors are, therefore, dependent upon the presence of light.

3. External Humidity

One of the basic principles involved in the diffusion of any material is the steepness of the concentration gradient between the two areas. Any increase in the atmospheric humidity surrounding a plant would decrease this gradient and thus decrease transpiration. If the atmosphere is saturated with water vapours, transpiration will cease. In green-houses the common practice is to water the walls and floors to ensure a high degree of humidity surrounding the plants and thus reduces the water loss from the plants. This reduces the possibility of wilting and results in better growth.

4. Air Circulation

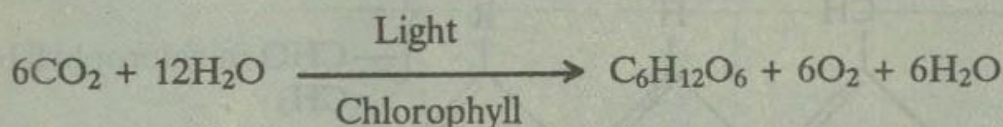
As water molecules diffuse out through the stomata, they tend to accumulate above these openings, decreasing the concentration gradient by increasing the external humidity. Air movement prevents such accumulation and brings drier air in contact with the leaves, thus maintaining high rate of transpiration.

5. Soil Moisture

If water is not readily available from the soil, the rate of transpiration may exceed the rate of absorption. Such a condition cannot exist for any length of time without wilting of the plant. This flaccid (limp) condition is a result of a decrease in turgor pressure of cells as water is lost more rapidly than it is replaced. The stomata therefore, close when the plant wilts, and transpiration decreases. The closure of stomata also affects carbon dioxide absorption and photosynthesis.

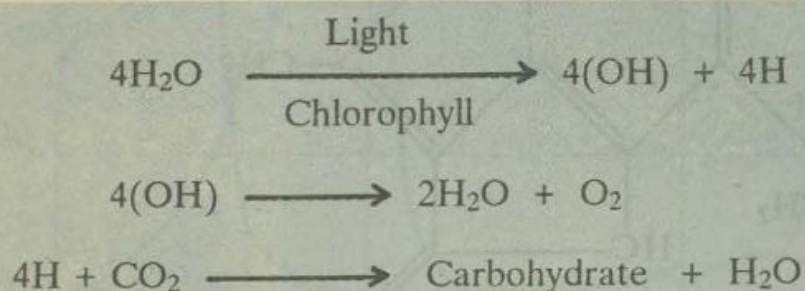
PHOTOSYNTHESIS

It is a process in green plants, in which organic food mainly carbohydrates are synthesized from water and carbon dioxide using energy absorbed from sunlight by the chlorophyll pigment. The reaction takes place in chloroplasts in green plants. The over all reaction is:



The products are glucose, molecular oxygen and water.

There are two distinct phases in photosynthesis, the **light reactions** and **dark reactions**. In green plants and blue-green algae, the light reactions involve the photolysis of water, producing hydrogen atoms and molecular oxygen. This oxygen, given off during photosynthesis, is the main source of atmospheric oxygen, essential for aerobic organisms. The main steps are as follows:



The hydrogen atoms produced are used to reduce coenzyme NADP (nicotinamide adenine dinucleotide phosphate) to NADPH and the energy released also forms ATP (adenosine triphosphate) from ADP (adenosine diphosphate) and inorganic phosphate. The ATP and NADPH is used up during the dark reactions in which carbon dioxide is fixed in the carbohydrate.

Chlorophyll

Chlorophyll is the central pigment in the photosynthetic process, that makes the plant body green, and appears to be confined to the grana of the chloroplast. There are several different kinds of chlorophyll, which differ from one another in details of their molecular structures. Chlorophyll 'a' occurs in all photosynthetic plants except pigment containing bacteria. In all autotrophic organisms except diatoms, brown, red and blue green algae, chlorophyll 'b' is found. Chlorophylls 'c', 'd' and 'e' are found only in algae and in combination with chlorophyll 'a'.

Chlorophyll is a large molecule with a central core of magnesium held in a porphyrin or tetra pyrrole ring structure. The four nitrogen atoms of the pyrroles are co-ordinated to a magnesium atom. Attached to the ring is a long insoluble carbon-hydrogen phytol side chain, which serves to anchor the molecule in the internal membranes of the chloroplast. With an iron atom replacing the magnesium and with different side chains the same structure is found in the haem fraction of haemoglobin and in the cytochrome which are involved in electron transport in mitochondria and chloroplast.

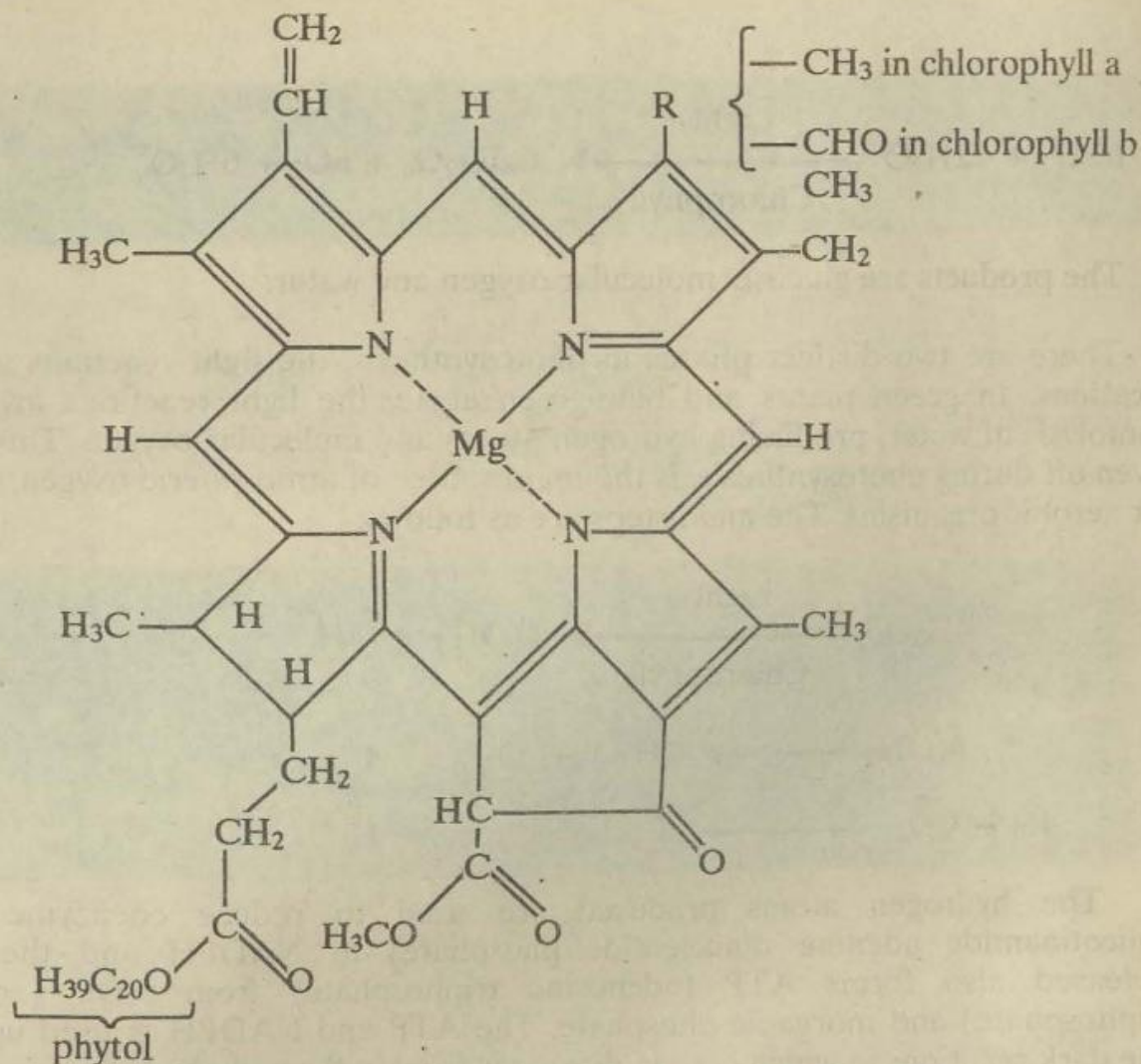
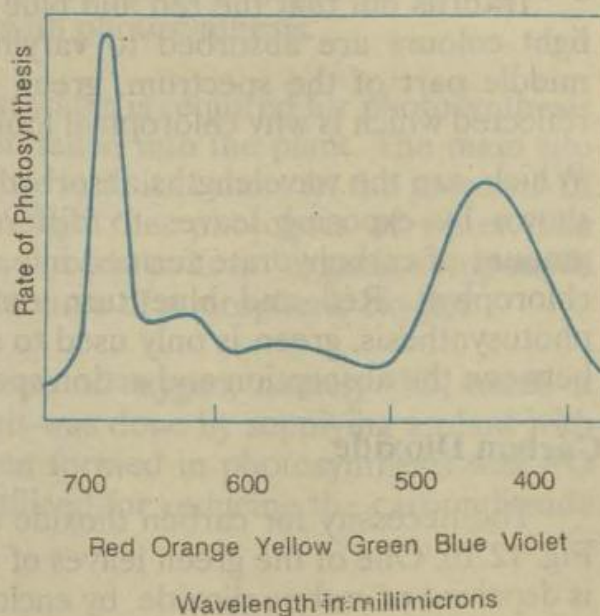
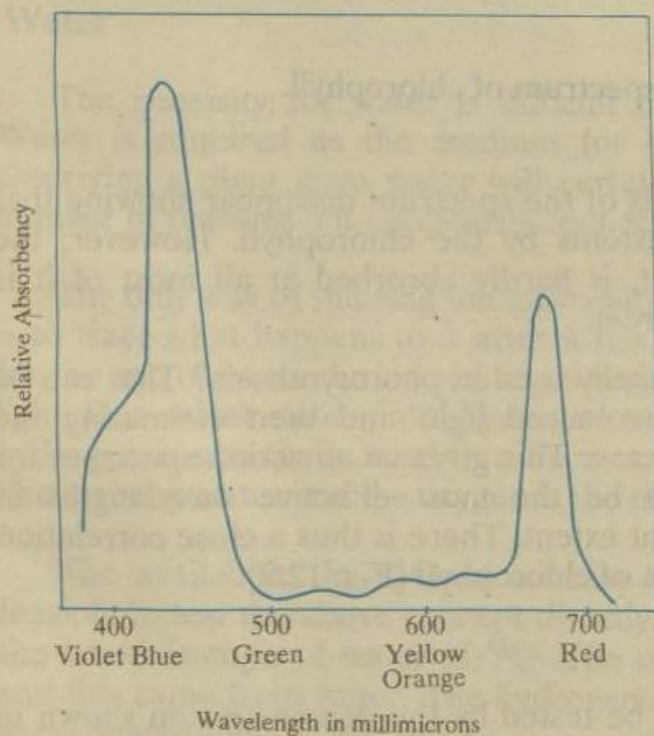
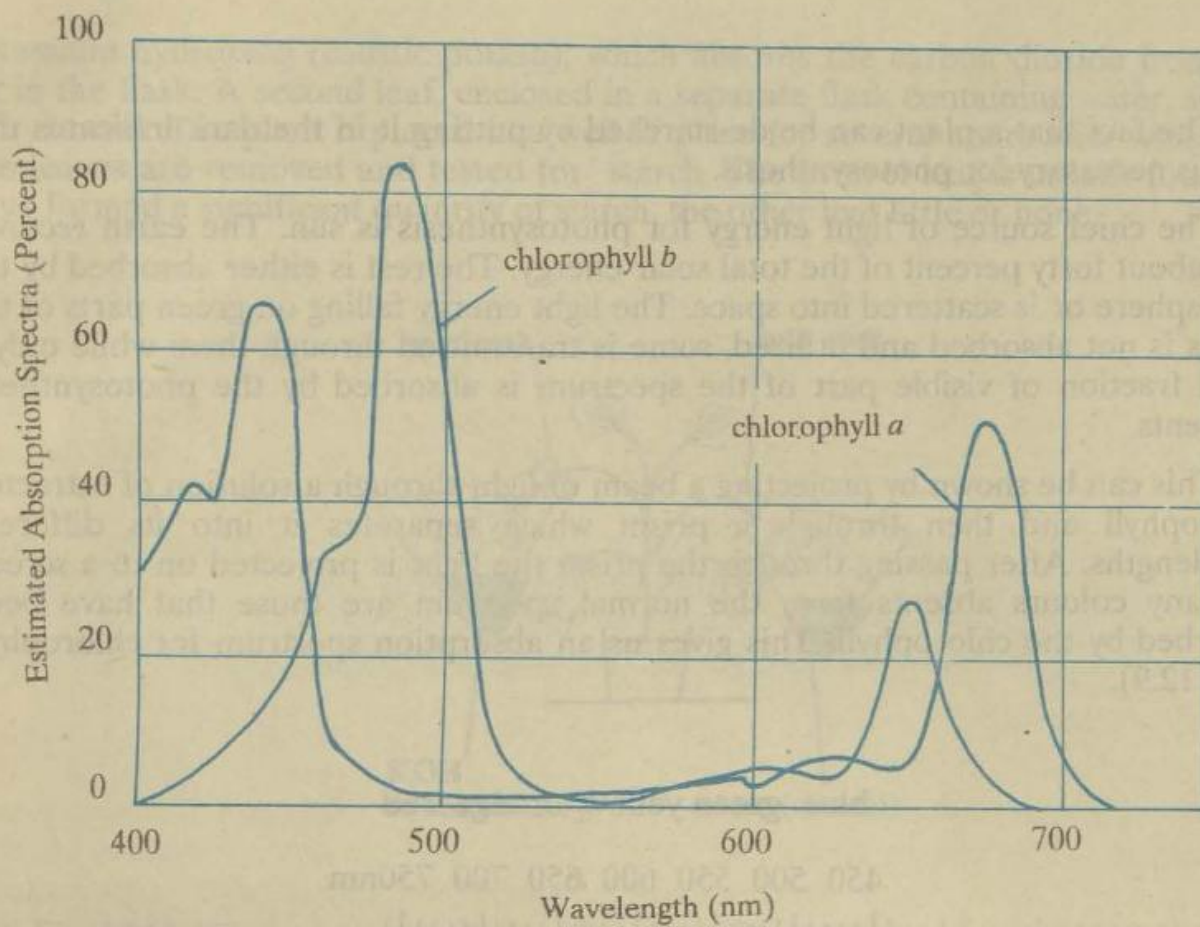


Fig.12.7 Structural formula of chlorophyll a and b.

The empirical formula of chlorophyll 'a' and chlorophyll 'b' are $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$ respectively. The structural formula of chlorophyll 'b' differs from chlorophyll 'a' in a substituent on one of the pyrroles. In chlorophyll 'b' there is a formyl or aldehyde group in place of a methyl group (Fig. 12.7).

Absorption Spectra of Chlorophyll

The principle photoreceptor in the chloroplast of green plants are chlorophyll 'a' and 'b' which show different absorption spectra. An absorption spectrum is a measure of the extent to which a given substance absorbs the light of different colours or wave lengths. Both chlorophyll 'a' and 'b' chiefly absorb light in the violet-blue and red parts of the visible spectrum, as determined with a spectrophotometer. There is still a large spectral region, from 500 to 600 nm, where the absorption of light is relatively weak (Fig. 12.8a). It must be noted that the action spectrum of photosynthesis, a measure of effectiveness of light of various wave lengths in driving photosynthesis is somewhat different from the absorption spectrum of chlorophyll 'a', (Fig. 12.8 b,c).



Light

The fact that a plant can be de-starched by putting it in the dark indicates that light is necessary for photosynthesis.

The chief source of light energy for photosynthesis is sun. The earth receives only about forty percent of the total solar energy. The rest is either absorbed by the atmosphere or is scattered into space. The light energy falling on green parts of the plants is not absorbed and utilized, some is transmitted through them while only a small fraction of visible part of the spectrum is absorbed by the photosynthetic pigments.

This can be shown by projecting a beam of light through a solution of extracted chlorophyll and then through a prism which separates it into its different wavelengths. After passing through the prism the light is projected on to a screen and any colours absent from the normal spectrum are those that have been absorbed by the chlorophyll. This gives us an absorption spectrum for chlorophyll (Fig. 12.9).

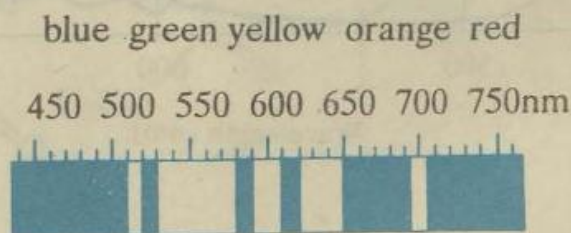


Fig.12.9 Absorption spectrum of chlorophyll.

It turns out that the red and blue ends of the spectrum disappear showing that light colours are absorbed to varying extents by the chlorophyll. However, the middle part of the spectrum, green light, is hardly absorbed at all most of it is reflected which is why chlorophyll looks green.

Which are the wavelengths absorbed actually used in photosynthesis? That can be shown by exposing leaves to different coloured light and then estimating the amount of carbohydrate formed in each case. This gives us an action spectrum for chlorophyll. Red and blue turn out to be the most effective wavelengths in photosynthesis, green is only used to slight extent. There is thus a close correlation between the absorption and action spectra of chlorophyll (Fig. 12.9).

Carbon Dioxide

The necessity for carbon dioxide can be tested by the demonstration shown in Fig. 12.10. One of the green leaves of a well watered potted plant such as *Geranium* is deprived of carbon dioxide by enclosing it in a flask containing a small volume of

potassium hydroxide (caustic potash), which absorbs the carbon dioxide from the air in the flask. A second leaf, enclosed in a separate flask containing water, serves as a control. The plant is placed in a well lit place for several hours after which the two leaves are removed and tested for starch. The control leaf is usually found to have formed a significant quantity of starch, the other leaf little or none.

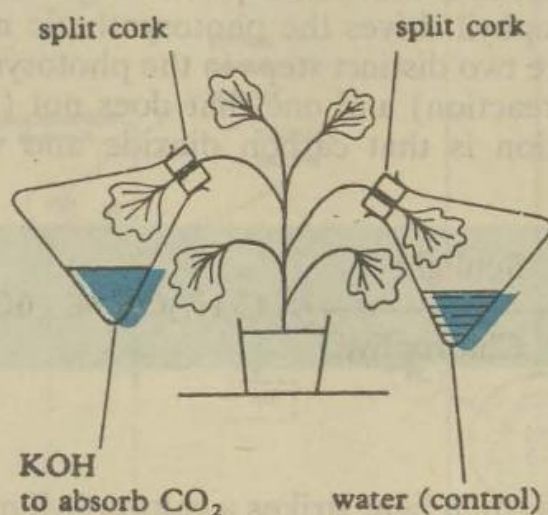


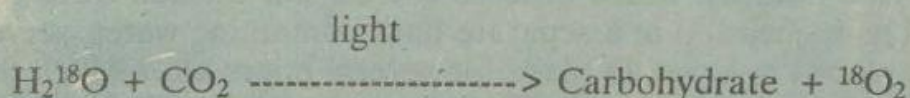
Fig. 12.10 Demonstration that carbon dioxide is required for photosynthesis

Water

The necessity for water is difficult to demonstrate by a simple experiment. Water is required as the medium for biochemical processes within the plant. Depriving a plant from water will certainly kill it, but this might be owing to a number of reasons, not necessarily connected with photosynthesis.

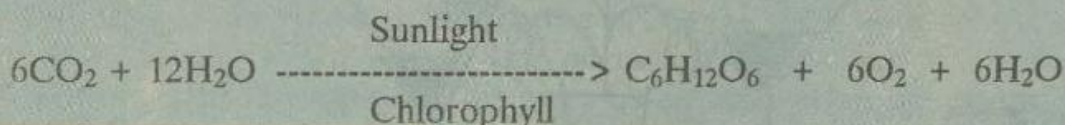
The only way of showing unequivocally that water is required for photosynthesis is to trace what happens to it after it has been taken into the plant. The main site for the use of water during photosynthesis is the leaf. It is there in the presence of light that water splits into hydrogen and oxygen i.e., photolysis of water. The hydrogen is eventually used to reduce carbon dioxide to form organic compounds like carbohydrates and the oxygen is the main source of atmospheric oxygen.

The availability in 1941 of a heavy isotope of oxygen, namely ^{18}O , made it feasible to test the above concept directly. This was done by supplying a plant with the heavy isotope of water H_2^{18}O . The oxygen formed in photosynthesis was ^{18}O and this came from water. The hydrogen is utilized for reducing the carbondioxide to carbohydrates.



Mechanism of Photosynthesis

Photosynthesis is a process that takes place in green plants and some other organisms. In fact, chlorophyll drives the photosynthetic mechanism by capturing the light energy. There are two distinct steps in the photosynthetic process, one that requires light (the light reaction) and one that does not (the dark reaction). The result of this vital reaction is that carbon dioxide and water are converted to glucose and oxygen.



The Light Reaction

Photosynthesis begins when light strikes a chlorophyll molecule and initiates the light reaction. The chlorophyll is activated by the light energy, so that two of its electrons move to a higher energy state and are then captured by an electron acceptor, called **plastoquinone** (PQ). The chlorophyll replaces its lost electrons by disrupting a water molecule and this disruption causes the water molecule to fall apart, releasing oxygen as a gas i.e. photolysis of water. This entire process takes place within the system designated as photochemical system II.

In photochemical system II, from the electron acceptor plastoquinone the electrons pass through an electron-transport chain. The chain consists of a series of electron acceptor molecules, which are cytochrome 'b' (cyt.b), cytochrome 'f' (cyt.f) and plastocyanin (PC). The each electron acceptor molecule is at a lower energy level than the earlier, so that the electrons progressively lose their energy as they are passed from one molecule to the next. Some of this energy is used to make ATP from ADP between cytochrome 'b' and cytochrome 'f' molecules. In this way ATP synthesis generated by light energy is called **photophosphorylation**.

Finally the electrons are passed along to another pigment system at the bottom of photochemical system I, light energy again boosts the electrons to another electron acceptor, called ferredoxin reducing substance (FRS), this one is at an even higher energy level than the last. From this acceptor the electrons are passed along to a nucleotide of adenine called NADP_{ox} (since it is in oxidized form), thus reducing it to $\text{NADPH}_{(\text{red})}$. You will notice that the electrons accepted by $\text{NADP}_{(\text{ox})}$, are still at a high energy level. The electron-transport and phosphorylation during light reaction, result in the Z-scheme (Fig. 12.11).

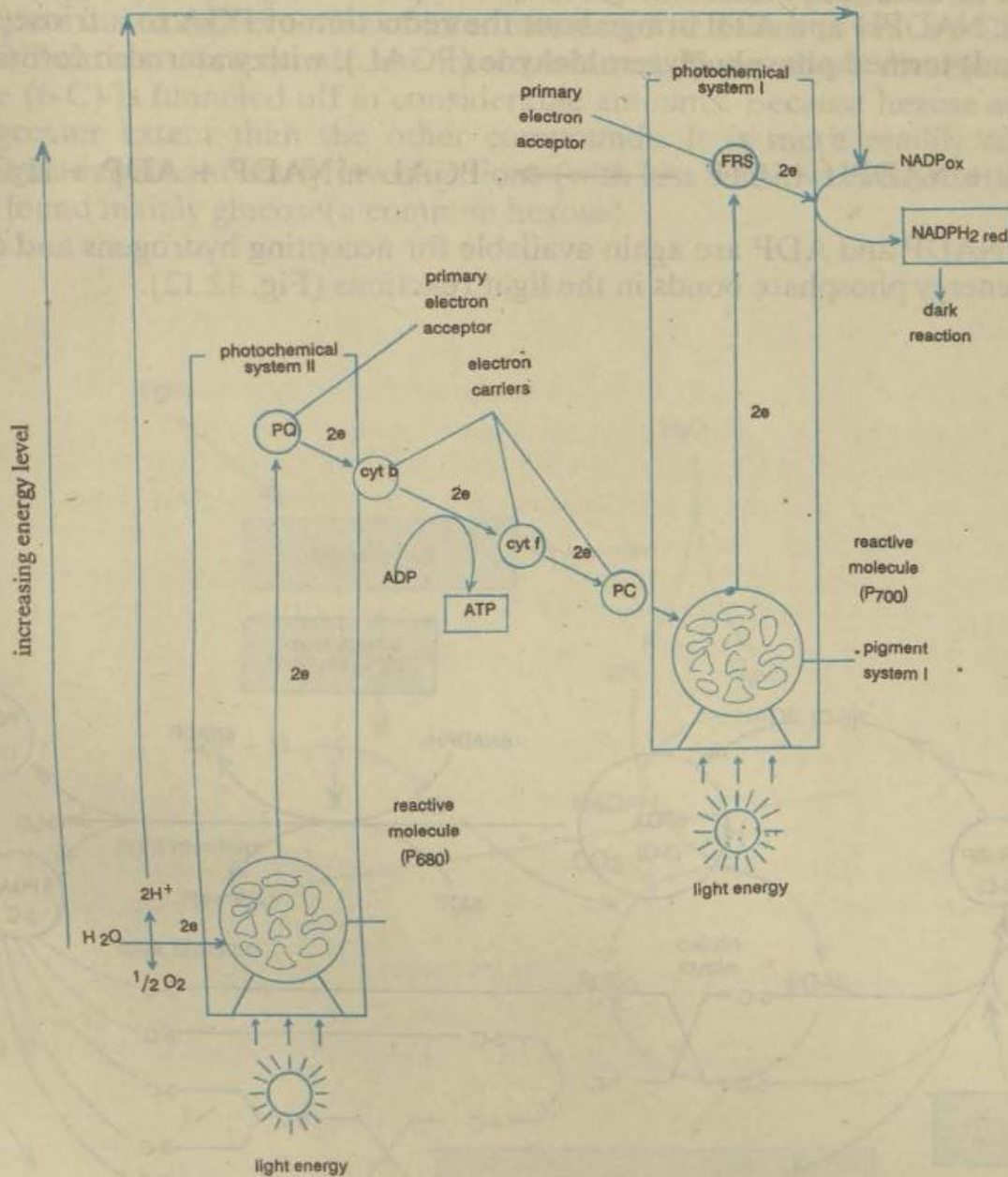


Fig. 12.11 Z-scheme of light reaction, takes place in the granum of the chloroplast.

Dark Reaction

As a first step in the dark reactions, carbon dioxide is added to a preexisting 5-carbon sugar phosphate (ribulose biphosphate, RuBP) forming an unstable 6-carbon compound, which immediately splits into two molecules of phosphoglyceric acid (PGA), the first identifiable product. This acid is a phosphorus-containing organic compound with three carbon atoms. It is at this stage that some of the

products of the light reactions begin to participate, and where energy (as ATP) is required. NADPH and ATP bring about the reduction of PGA to a triose(3-carbon compound) termed **phosphoglyceraldehyde (PGAL)**, with water also forming in the reaction.



The NADP and ADP are again available for accepting hydrogens and electrons or high-energy phosphate bonds in the light reactions (Fig. 12.12).

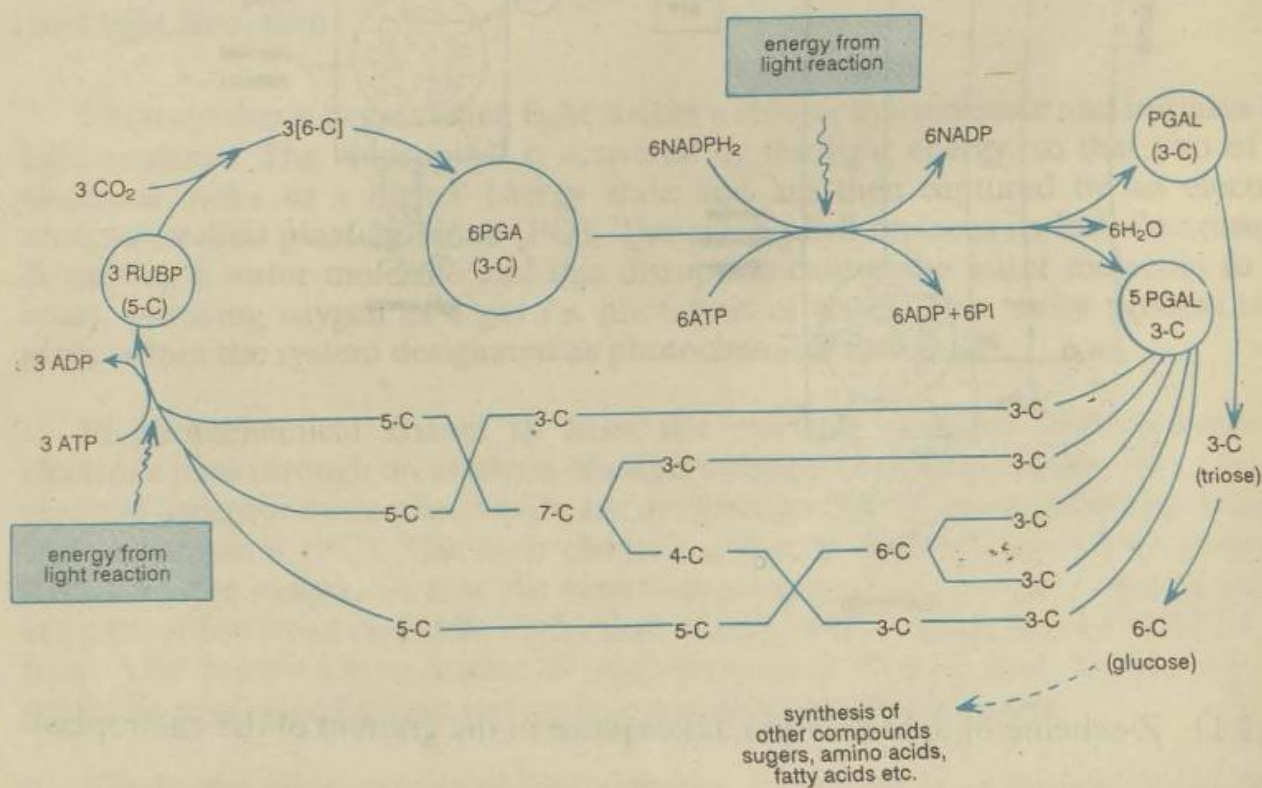


Fig. 12.12 Calvin cycle (Dark Reaction) takes place within stroma of the chloroplast.

The many phosphoglyceraldehyde (PGAL) molecules produced in this fashion participate in a complex series of inter connected reactions in which 3-C, 4-C, 5-C, 6-C, and 7-carbon compounds are interconverted. From these diverse compounds hexose (6-C) is funneled off in considerable amounts. Because hexose accumulates to a greater extent than the other compounds. It is more readily observed on chemical analysis and early investigations (with less sensitive methods than present ones) found mainly glucose (a common hexose).

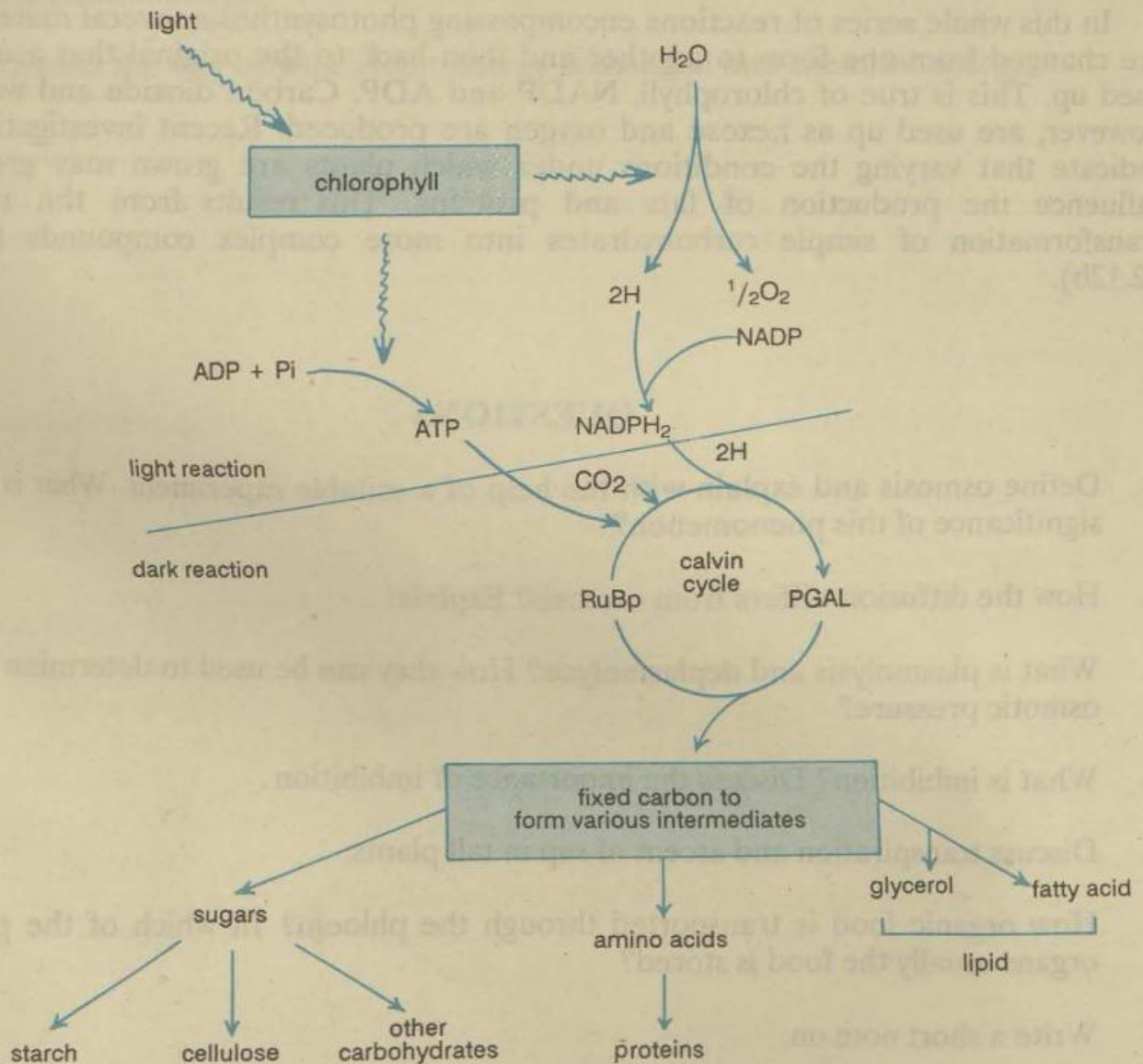


Fig. 12.12 (b) Summary of photosynthesis.

During these interconversions, ribulose is also formed. Phosphorylation occurs, using ATP from the light reactions, and ribulose biphosphate (RuBP) is then available to accept CO_2 .

In fact this series of complex reactions is cyclic. Calvin and his colleagues were able to elucidate the pathway of carbon in photosynthesis by the use of radioactive carbon (C_{14}) in carbon dioxide, RuBP is used up and reformed, and hexose is drawn off the cycle. Since glucose is readily converted to other materials, amino acids, organic acids, and other compounds appear quite rapidly in the cell during photosynthesis.

In this whole series of reactions encompassing photosynthesis several materials are changed from one form to another and then back to the original that are not used up. This is true of chlorophyll, NADP and ADP. Carbon dioxide and water, however, are used up as hexose and oxygen are produced. Recent investigations, indicate that varying the conditions under which plants are grown may greatly influence the production of fats and proteins. This results from the rapid transformation of simple carbohydrates into more complex compounds (Fig. 12.12b).

QUESTIONS

1. Define osmosis and explain with the help of a suitable experiment. What is the significance of this phenomenon?
2. How the diffusion differs from osmosis? Explain!
3. What is plasmolysis and deplasmolysis? How they can be used to determine the osmotic pressure?
4. What is imbibition? Discuss the importance of imbibition.
5. Discuss transpiration and ascent of sap in tall plants.
6. How organic food is transported through the phloem? In which of the plant organs usually the food is stored?
7. Write a short note on:
 - (a) Root pressure
 - (b) Transpiration pull
8. What is transpiration? Why it is said to be necessary evil?

9. What are different types of transpiration?
10. Discuss the influence of various environmental factors on transpiration.
11. What is the role of chlorophyll in plants? Give its components and the role they play.
12. How CO_2 is fixed during photosynthesis to form carbohydrate?
13. Discuss the modern concept of mechanism of photosynthesis, keeping in view the biochemistry.
14. Discuss the way by which light energy is changed into chemical energy.

DIVERSITY IN FUNCTION: PLANTS RESPIRATION, GROWTH

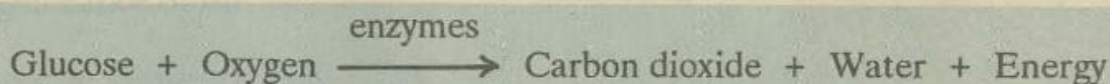
13

RESPIRATION

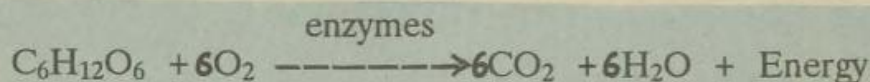
All living cells respire. **Respiration** refers to the series of complex oxidation-reduction reactions, whereby living cells obtain energy through the breakdown of organic material. There are two kinds of respiration as described below:

(1) Aerobic Respiration

Respiration that proceeds in the presence of abundant gaseous oxygen is termed aerobic respiration. The oxygen is reduced (to water) as the substrate, usually glucose, is oxidized. The overall reaction may be indicated as follows.



The amount of energy produced when a glucose molecule is burned or oxidized to carbon dioxide and water is the same as the amount stored in that molecule during photosynthesis. When glucose is oxidized, in a cell, some of this energy is in the form of heat, which is wasted as far as the cell is concerned. The water is usually retained within the cell, while the carbon dioxide diffuses out of the cell or is used in photosynthesis. In most organisms this "metabolic water" is of no significance because of the large quantities of water obtained in other ways (e.g., absorption). A broken arrow appears in the overall equation to emphasize that many steps are involved:

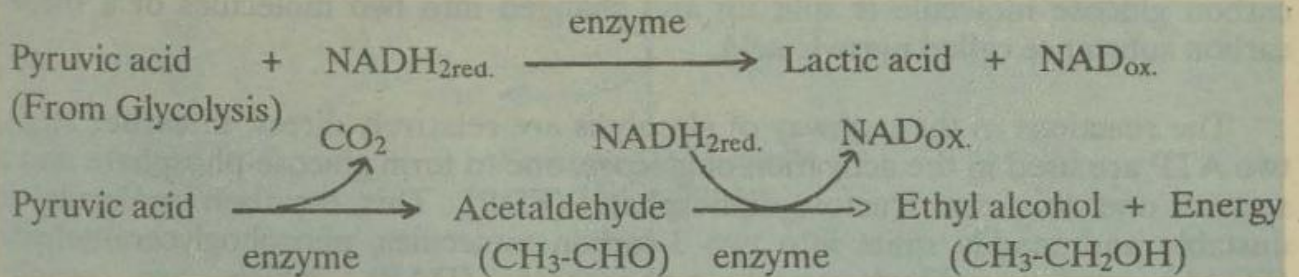


(2) Anaerobic Respiration

Many micro-organisms, cells of higher plants, and animal tissues are capable of carrying on incomplete oxidation-reduction reactions in the absence of gaseous

oxygen. This is termed as **anaerobic respiration**, or **fermentation**, and the energy released from the substrate is a result of its molecular rearrangement. The end products are not carbon dioxide and water but various organic compounds, such as lactic acid and ethyl alcohol. As with aerobic respiration, fermentation results in the production of energy, some of which is then available to the cell.

In animals the product of anaerobic respiration is lactic acid and in yeast, the respiratory products are carbon dioxide and ethyl alcohol. The $\text{NADH}_{2\text{red}}$ gives up its two added hydrogens to form the alcohol and is then free to return as NAD_{ox} to pick two more hydrogen atoms from a new pyruvic acid molecule.



Process of Respiration

Briefly, what happens during respiration is that the glucose molecule is split, the

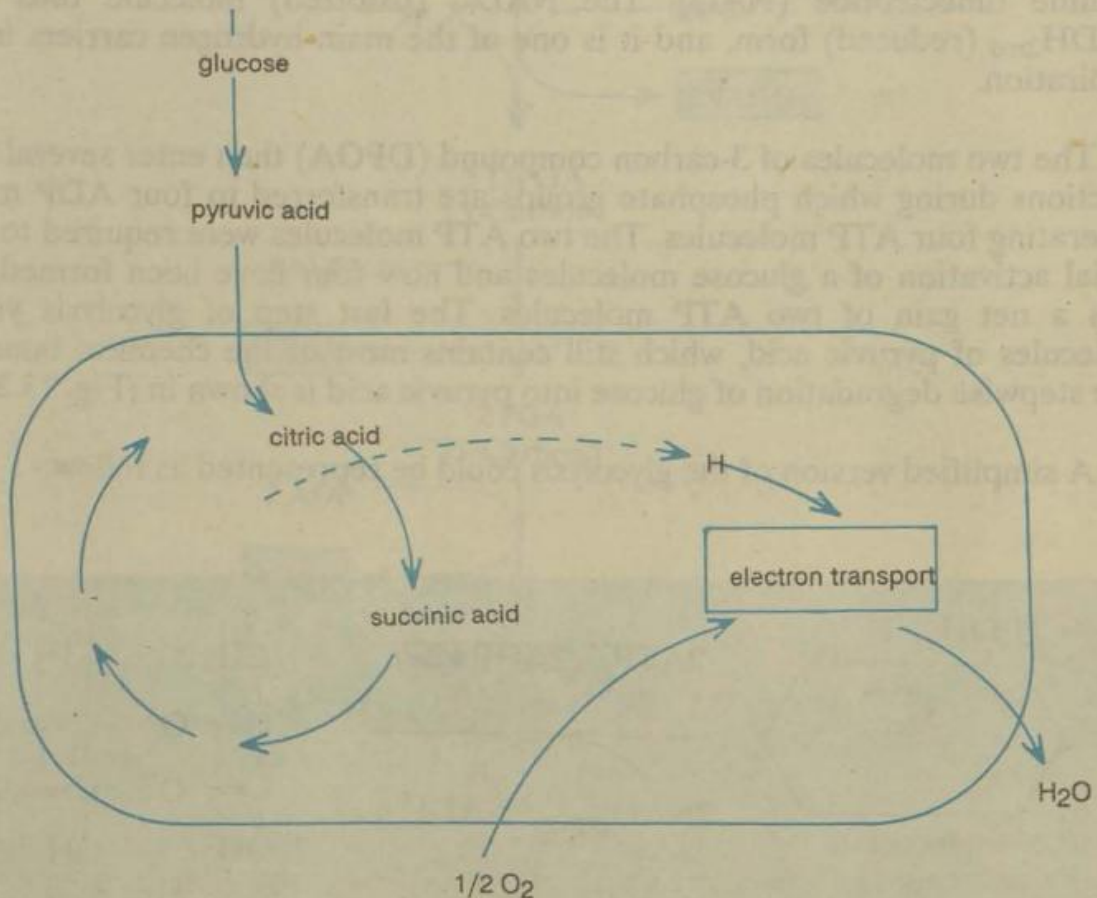


Fig. 13.1 Summary of the role of the mitochondria in respiration.

hydrogen atoms (both protons and electrons) are transferred from the carbon atoms to oxygen atoms and the energy released as a result of this transfer is used to convert ADP to ATP. The process of trading glucose for ATP is referred to as cellular respiration, since it takes place within the cell. Cellular respiration takes place in three stages: glycolysis, the Krebs cycle, and the electron transport chain. Lets look at these steps in more detail (Fig. 13.1).

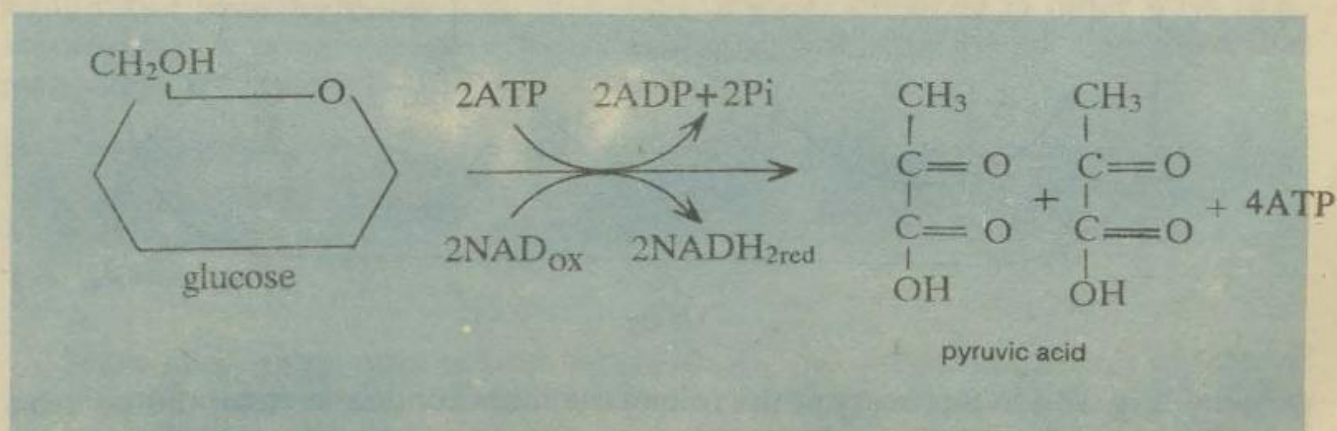
Glycolysis

The process of glycolysis takes place in the cytoplasm. At this stage, the six-carbon glucose molecule is split up and changed into two molecules of a three-carbon substance called **pyruvic acid**.

The reactions in the pathway of glycolysis are relatively direct. In earlier steps, two ATP are used in the activation of glucose, one to form glucose-phosphate and a second one to form fructose-diphosphate (FDP). This 6-carbon molecule is unstable and readily splits into two 3-carbon molecules, phosphoglyceraldehyde (PGAL) and a dihydroxyacetone-phosphate (DAP), which are readily interconvertable by an enzyme. Each PGAL molecule picks up an inorganic phosphate group from the surrounding cytoplasm to become diphosphoglyceric acid (DPGA), which is oxidized to yield hydrogen to a molecule of nicotinamide adenine dinucleotide (NAD). The NAD_{ox} (oxidized) molecule thus becomes $\text{NADH}_{2\text{red}}$ (reduced) form, and it is one of the main hydrogen carriers in cellular respiration.

The two molecules of 3-carbon compound (DPGA) then enter several chemical reactions during which phosphate groups are transferred to four ADP molecules, generating four ATP molecules. The two ATP molecules were required to start the initial activation of a glucose molecules and now four have been formed, there is thus a net gain of two ATP molecules. The last step of glycolysis yields two molecules of pyruvic acid, which still contains most of the chemical bond-energy. The stepwise degradation of glucose into pyruvic acid is shown in (Fig. 13.2 a,b).

A simplified version of the glycolysis could be represented as follow:-



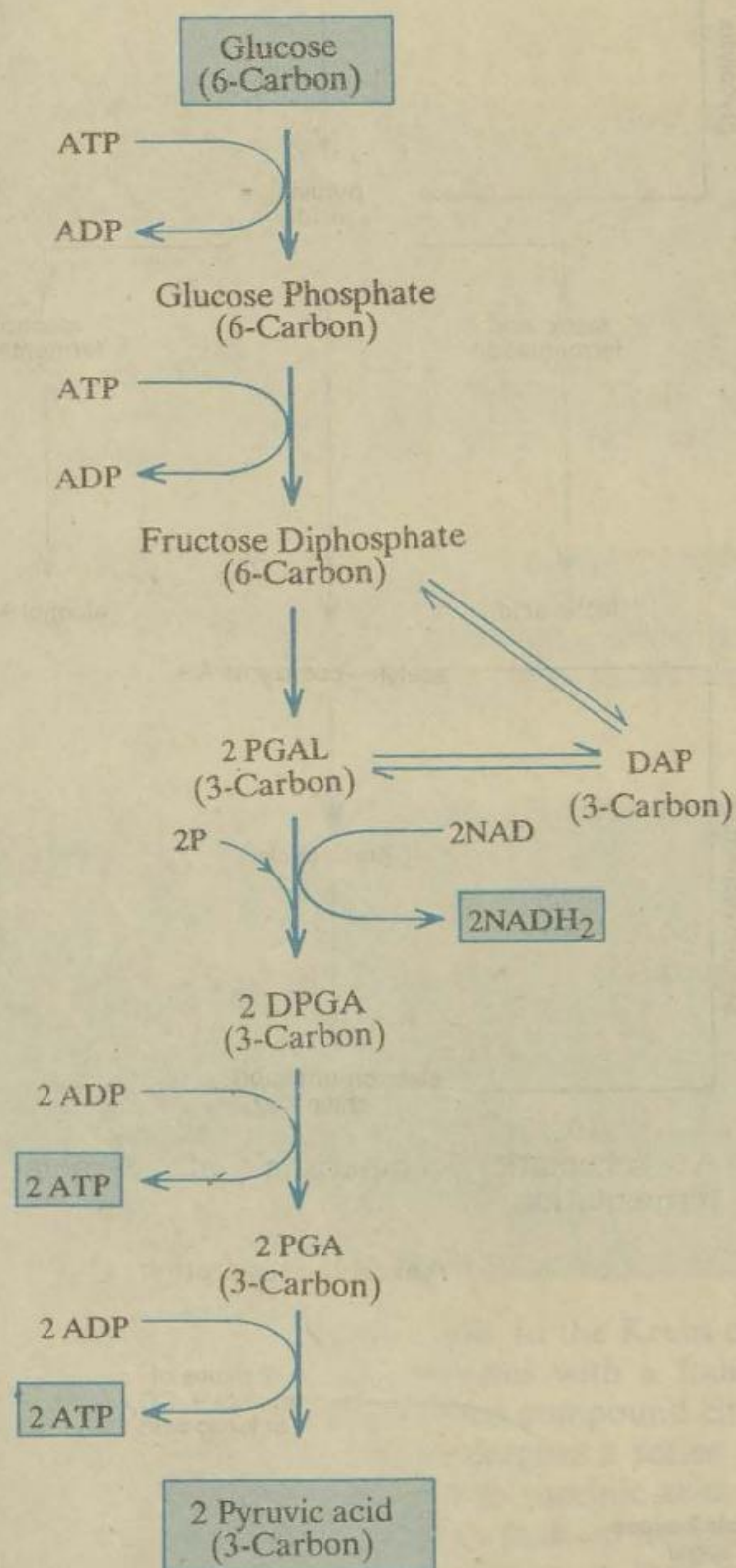


Fig 13.2 a Glycolysis the oxidative breakdown of glucose into two molecules of pyruvic acid. All reactions are basically reversible because the products are utilized in various ways, and thus continually removed, the reactions proceed primarily as indicated by arrows.

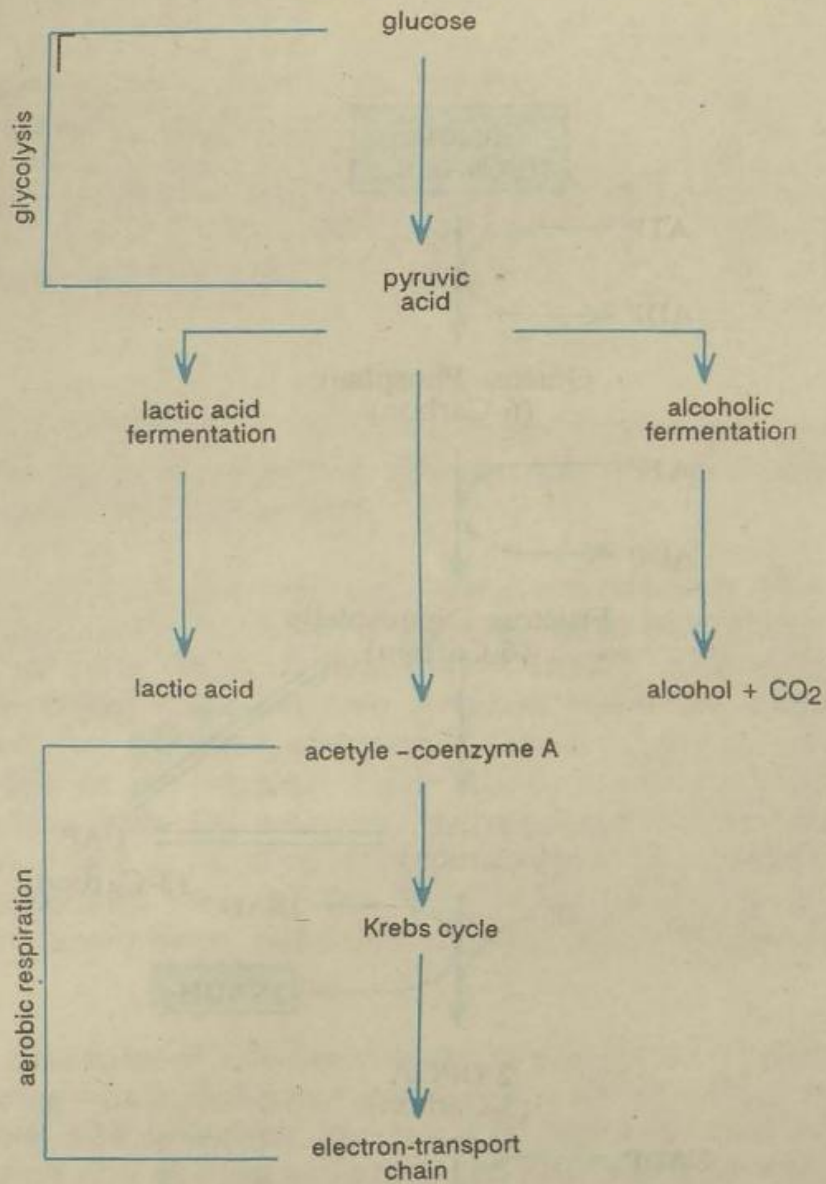
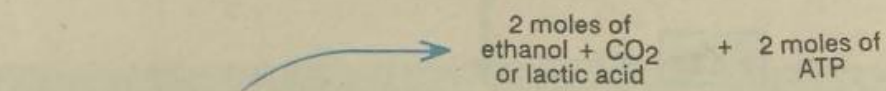


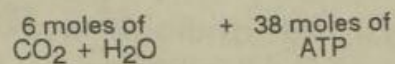
Fig.13.2(b) A schematic comparison of aerobic respiration and fermentation.

Anaerobic respiration



1 mole hexose sugar

6 moles of O₂

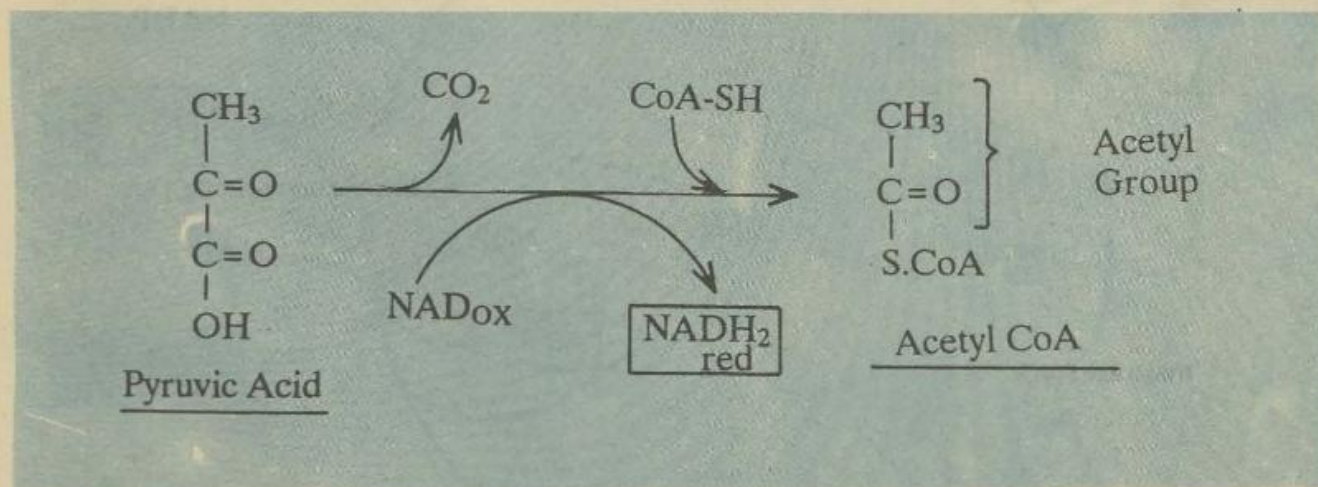


Aerobic respiration

The Krebs Cycle

We know that in the absence of oxygen glucose molecule provides an aerobic organism with only two molecules of ATP to carry out its functions. But if oxygen is present, it is a whole new game. The pyruvic acid will go through a series of reactions that generates thirty six more ATPs. In aerobic respiration the two pyruvic acid molecules formed from the glucose are shunted into the Krebs cycle, named for its British discoverer Sir Hans Krebs. Eventually the high-energy pyruvic acid is broken down completely to the simple end products, carbon dioxide and water, having released most of its energy along the way. Both the Krebs cycle and the next stage of respiration, the electron - transport chain, take place in tiny structures within the cell called mitochondria.

If oxygen is present, the three - carbon pyruvic acid molecule produced by glycolysis oxidizes - with NAD molecules again accepting two hydrogen - and lose one carbon in the form of carbon dioxide. The remaining, two carbon fragment, acetic acid, then unites with coenzyme A (COA-SH,) to form acetyl - COA as represented below:



It is actually the acetyl- CoA that enters the Krebs cycle. In the Krebs cycle the acetyl group separates from its CoA enzyme and combines with a four-carbon molecule called oxaloacetic acid. The result is the six-carbon compound citric acid, the common acid of lemons and limes. The citric acid undergoes a series of cyclic changes, being converted first to a ketoglutaric acid, then to succinic acid, fumaric acid, malic acid and finally to oxaloacetic acid recycled to pick up another acetyl group from the next acetyl-CoA molecule. The cycle continues as long as acetyl-CoA is available. This process is illustrated in (Fig. 13.3 a,b).

Carbohydrates (starch), proteins and lipids can all be digested to simpler compounds, such as sugars, aminoacids, and glycerol and fatty acids, respectively. These simpler compounds can be changed into molecules that can be taken up in the Krebs cycle and made to yield ATP (Fig 13.3b).

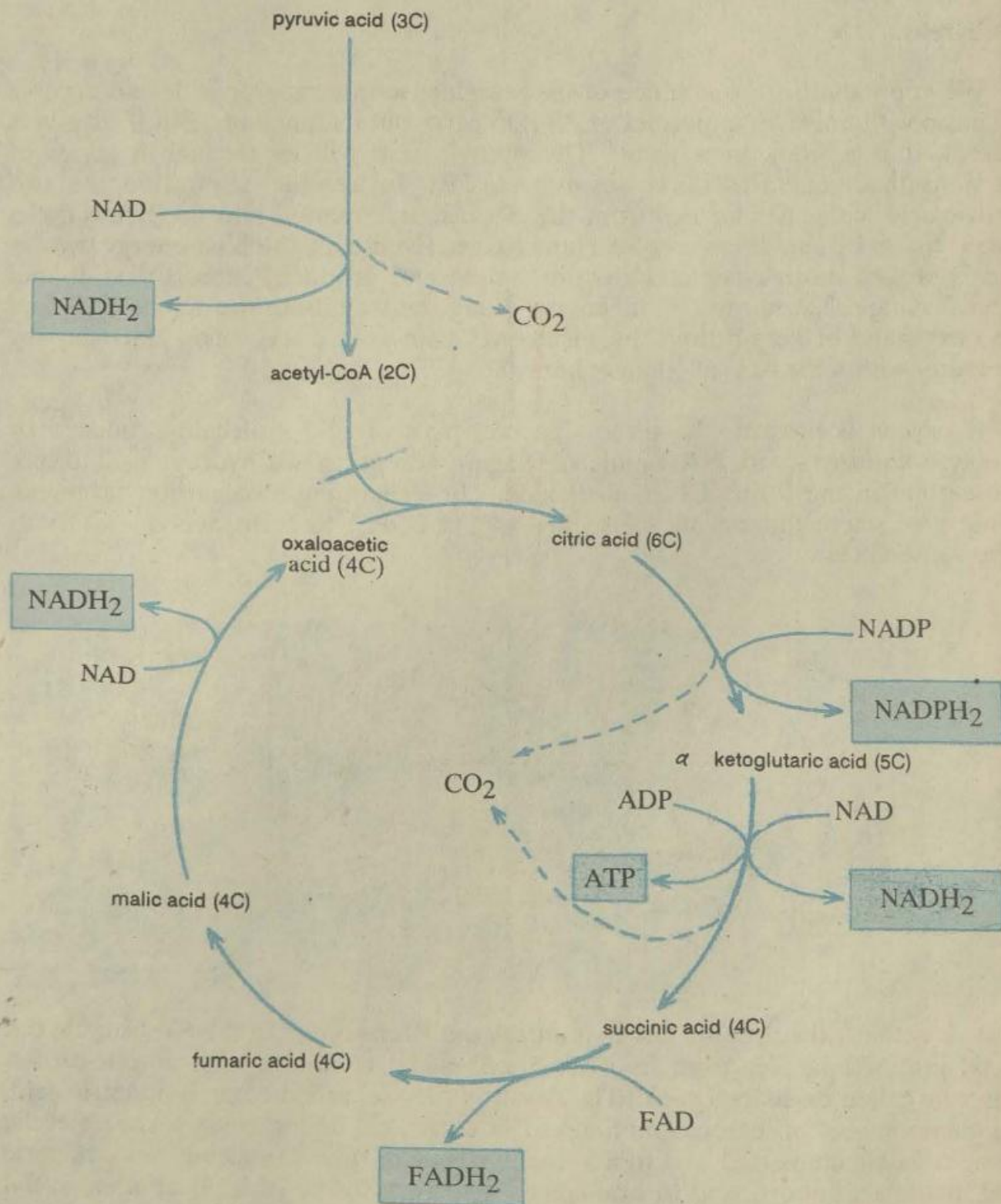


Fig. 13.3 a Summary of the Krebs cycle. The principal feature of the Krebs cycle is the progressive removal of the hydrogen (protons and electrons) from which energy is derived. NAD (Nicotinamide adenine dinucleotide), FAD (flavin adenine dinucleotide).

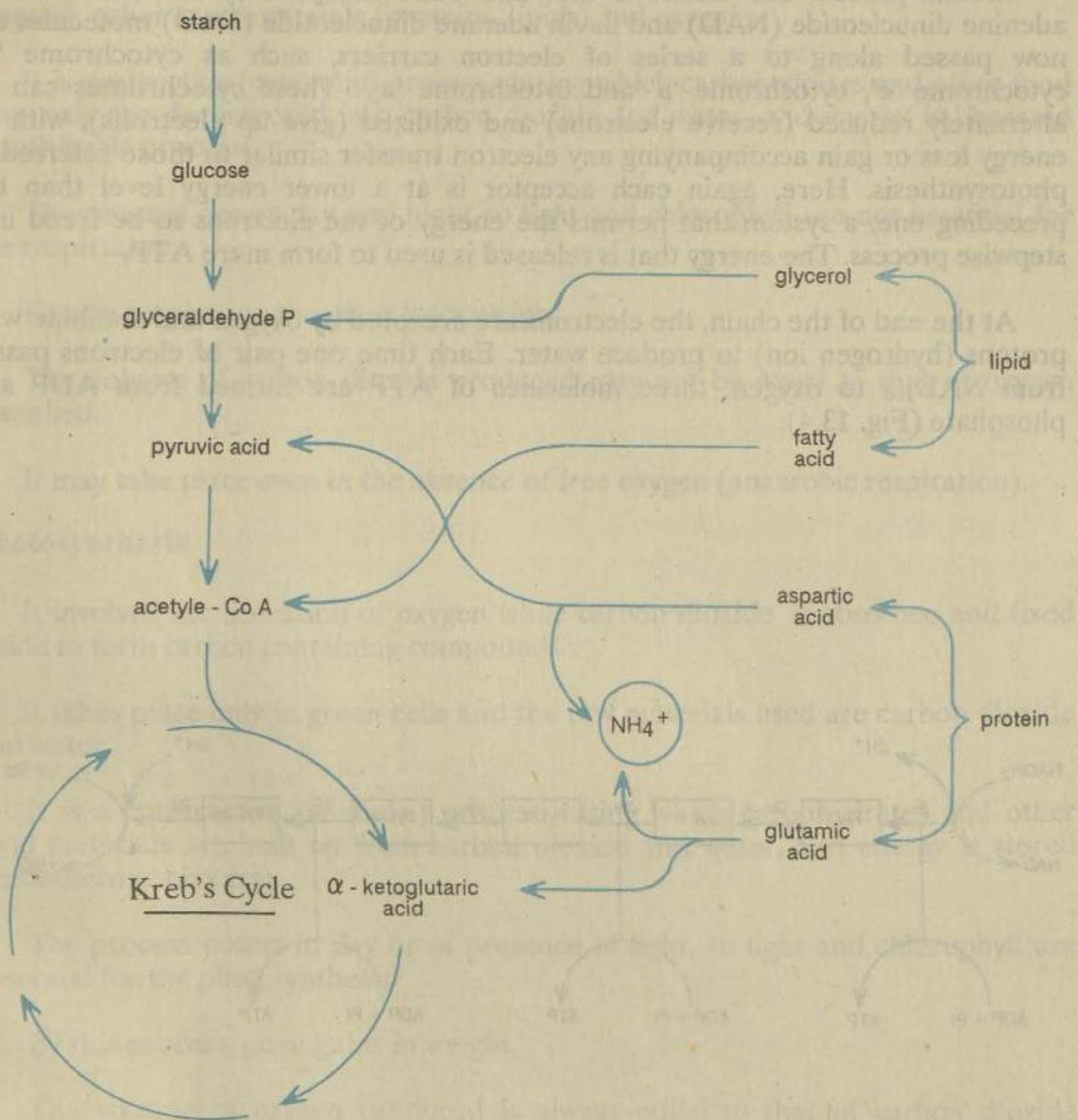


Fig. 13.3 (b) Some entry points of food-to-energy conversion.

Electron Transport Chain

The last stage of aerobic respiration is the electron-transport chain, which takes place in the mitochondria, where most respiratory energy exchange occurs, there is an orderly arrangement of hydrogen acceptors accompanied by appropriate enzymes. The series of carriers is called the **electron-transport chain**.

In this process the electrons that had been accepted by the nicotinamide adenine dinucleotide (NAD) and flavin adenine dinucleotide (FAD) molecules are now passed along to a series of electron carriers, such as cytochrome 'b', cytochrome 'c', cytochrome 'a' and cytochrome 'a₃'. These cytochromes can be alternately reduced (receive electrons) and oxidized (give up electrons), with an energy loss or gain accompanying any electron transfer similar to those referred to photosynthesis. Here, again each acceptor is at a lower energy level than the preceding one, a system that permits the energy of the electrons to be freed in a stepwise process. The energy that is released is used to form more ATP.

At the end of the chain, the electrons are accepted by oxygen and combine with protons (hydrogen ion) to produce water. Each time one pair of electrons passes from NAD_{red} to oxygen, three molecules of ATP are formed from ADP and phosphate (Fig. 13.4).

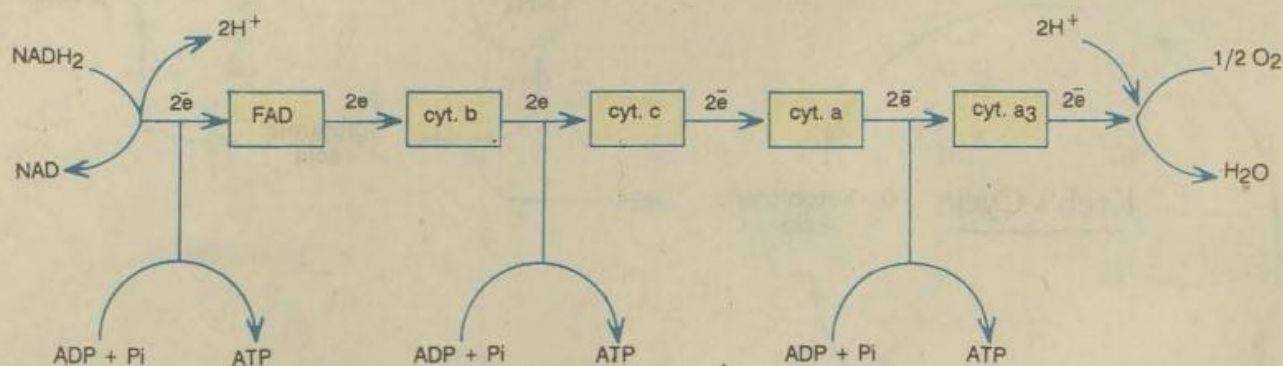


Fig. 13.4 The respiratory electron transport chain.

Comparison between Respiration and Photosynthesis

Respiration

1. It involves the absorption of oxygen and liberation of carbon dioxide and water vapours as a result of oxidation of carbon containing compounds.

2. It takes place in all living cells and the raw materials used are carbohydrates (sugars), other food materials (proteins, lipids) and oxygen.
3. It is destructive (catabolic) process, during which carbohydrates and other food materials are decomposed into carbon dioxide and water, and energy is liberated (exothermic process).
4. The process occurs day and night so light and chlorophyll are not essential for the respiration.
5. Due to respiration the plant loses weight.
6. The volume of carbon dioxide produced may not be equal to that of oxygen absorbed.
7. It may take place even in the absence of free oxygen (anaerobic respiration).

Photosynthesis

1. It involves the liberation of oxygen while carbon dioxide is absorbed and fixed inside to form carbon containing compounds.
2. It takes place only in green cells and the raw materials used are carbon dioxide and water.
3. It is a constructive (anabolic) process during which carbohydrates and other food materials are built up from carbon dioxide and water, and energy is stored (endothermic process).
4. The process occurs in day or in presence of light, so light and chlorophyll are essential for the photosynthesis.
5. By this process, plant gains in weight.
6. The volume of oxygen produced is always equal to that of carbon dioxide absorbed.
7. It does not take place in the absence of carbon dioxide.

GROWTH AND REPRODUCTION

GROWTH

The term growth refers to two basic factors of a plant development: (1) an increase in the number of cells as a result of cell division, and (2) an enlargement

and differentiation of existing cells accompanied by an increase of cellular components. No sharp distinction exists between these phases of growth.

Growing Points: (Meristematic Regions)

Speaking generally, the process of growth is initiated in regions of the plant in which cell division takes place, such regions are known as **meristems**. Apical meristems are present at the tips of roots and stems, and growth initiated by such apical meristems is known as **primary growth**, to distinguish it from **secondary growth**, initiated by the **cambium**, which are essentially lateral meristems. Generally the apical meristem is responsible for growth resulting in an increase in length and in the production of branches and other lateral parts, such as the leaves and flowers. The cambium, on the other hand, is responsible for increase in diameter. Since their cell divisions are typically in planes parallel to the long axis of the stem or root. Meristematic regions of a stem which are separated by mature tissues, as in the internodes of grasses are known as **intercalary meristems**.

Stem

The tip of the stem as seen in longitudinal section possess at its apex a region of initial cells which, by repeated divisions produce the tissues of the stem. Immediately below or lateral to the zone of the initial cells are more cells which are still actively engaged in division. In this region, the leaf primordia are produced as lateral protuberances which arise at regular intervals below the apex. At still greater distances below the apex, cell division becomes progressively less dominant, and cell enlargement becomes the dominant cellular activity. As cells enlarge to their full size, they differentiate that is they assume the special structural features which fit them for their particular physiological function (Fig 13.5).

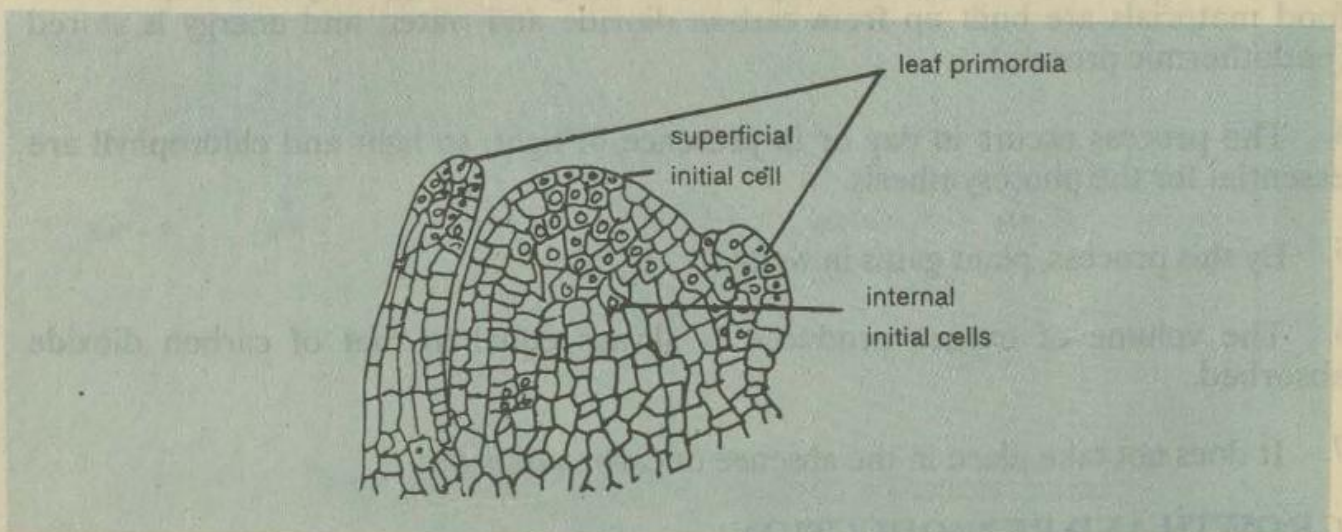


Fig 13.5 A stem apex of the bamboo, a sinocalamus, showing the regions of initial

Root

The meristems of roots are simpler to those of stems because they lack the complexity of leaf formation. The initial zone of the root meristem, like that of the stem, may consist of a single cell or it may consist of two, three, or even four layers which tend to produce different portions of the root. Thus, the most apical layer of initial cells may produce only root cap cells, or more commonly, root cap and epidermis of the root. The innermost layer of initials may similarly produce the central portion of the root, while the central layer of initials may principally form the root cortex. As in the shoot, the initial zone of the root is subtended by a region of continued meristematic activity. In this region, some specialization into the ultimate elements of root structure is evident.

Stages of Growth

The growth of a multicellular plant involves both increase in cell number by cell division and an increase in cell size. In the apical regions of shoots and roots, cell

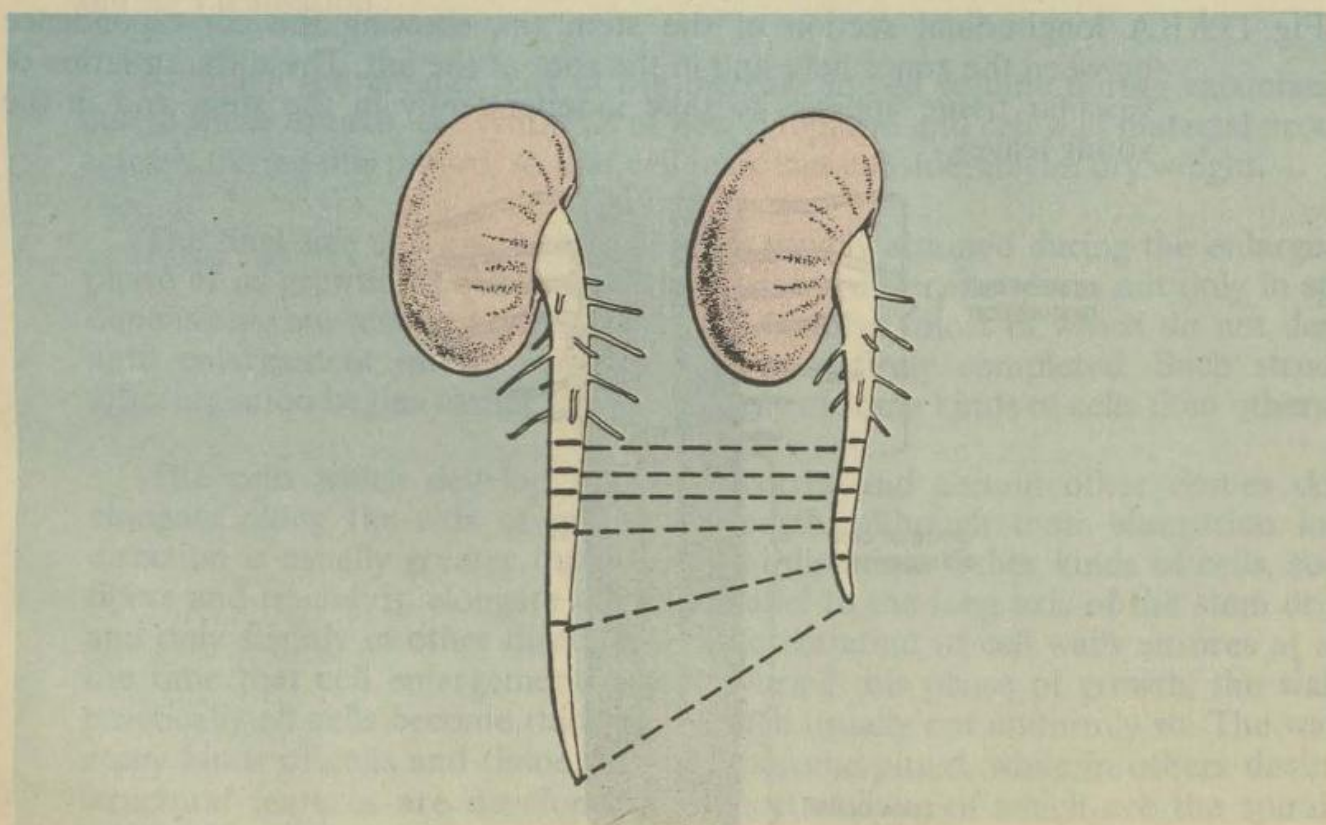


Fig. 13.6 a Demonstration of growth regions. Equidistant marks on the growing root (left) get separated unequally (right). the distance between marks at the tip and the base are short, showing thereby that, growth is slow in these regions. (zone of cell division and cell differentiation, respectively). Much separated marks behind the tip indicate rapid growth in this region (zone of the cell enlargement).

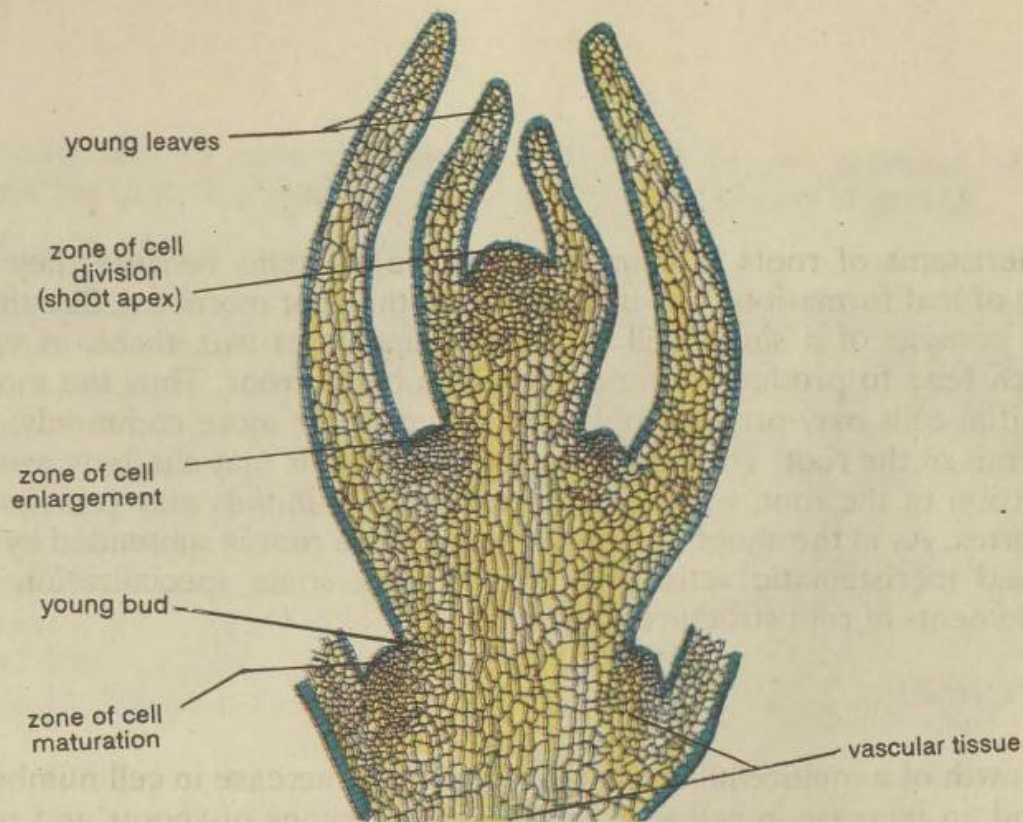


Fig. 13.6 b A longitudinal section of the stem tip, showing the correspondence between the zones here and in the root at the left. The differentiation of vascular tissue appears to take independently in the stem and in the young leaves.

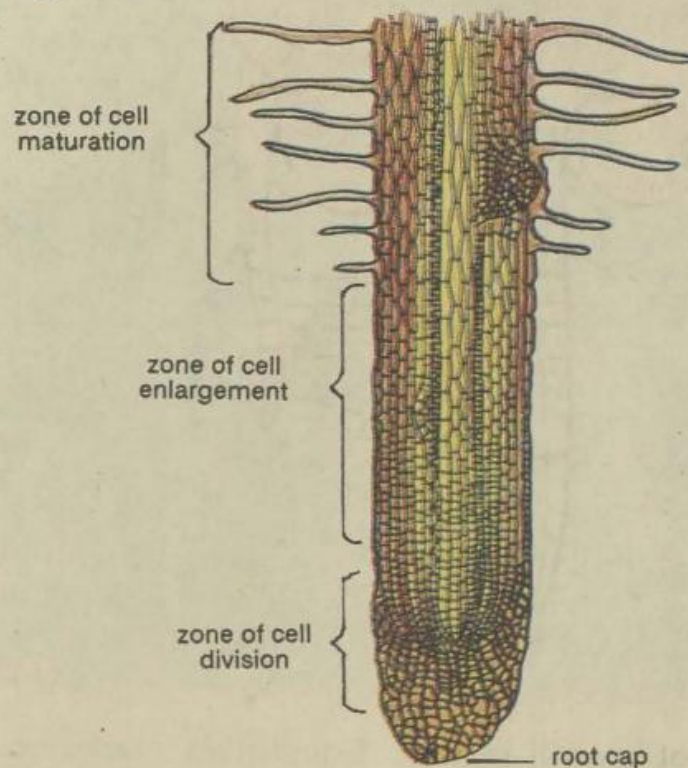


Fig. 13.6 c A longitudinal section of root tip, showing the zone of growth and differentiation correlate with the changes in spacing marks on the growing root.

division occurs most intensively towards the extreme tip of both organs, whereas the region of most rapid increase in cell size is in a zone few millimetres back from the tip.

In the tip regions of roots and shoots in which cell division predominates, the cells are relatively small, and have prominent, spherical nuclei lying towards the centre of the cytoplasm, which are non-vacuolated and tend to be densely staining, the walls are thin. As a result of division, each daughter cell proceeds to enlarge but such growth involves the synthesis of cytoplasm and cell wall material (Fig. 13.6).

At a certain distance from the apex, in both shoots and roots, the process of vacuolation commences and as a result of this process the cells enlarge. In some tissues cells may increase up to 150-fold in total volume during vacuolation. This great extension in cell size is linked with great uptake of water and is essentially governed by osmosis, there is considerable evidence that in vacuolating cells the wall pressure is reduced by increased plasticity of the cell wall at this time. As a result of its increased plastic extensibility the wall undergoes irreversible elongation during vacuolation.

Although the greater part of the increase in cell volume during vacuolation is due to water uptake, the synthesis of new cytoplasm and cell wall material proceeds actively during this period, so that cell increases considerably in dry weight.

The final size of a given type of cell is usually attained during the enlargement phase of its growth. The cells of various tissues differ, however, not only in spatial dimensions, but also in various structural features, most of which do not develop until enlargement of the cell is nearly or entirely completed. Such structural differentiation begins earlier in the ontogeny of some kinds of cells than others.

The cells which develop into pith, cortex and certain other tissues do not elongate along the axis of growth in length, although their elongation in this direction is usually greater than the radial direction. Other kinds of cells, such as fibers and tracheids, elongate greatly parallel to the long axis of the stem or root, and only slightly in other directions. Differentiation of cell walls ensures at about the time that cell enlargement ceases. During this phase of growth, the walls of practically all cells become thicker, although usually not uniformly so. The walls of many kinds of cells and tissue elements become pitted, while in others distinctive structural features are developed, the most striking of which are the spiral and other characteristic thickenings of the walls of the xylem vessels (Fig 13.6 b,c).

Physiology of Growth

Since growth involves various energy requiring processes, including protein synthesis, it is not surprising to find that rapidly elongating tissues have a high respiration rate, when compared with mature tissues on the basis of equal volumes

of tissue. Although when expressed per cell the respiration rate of mature cells may be greater than that of meristematic cells. Moreover, growth requires aerobic conditions and an adequate supply of carbohydrates, both as an energy source and as structural material. The role of growth hormones in cell division and cell extension is also vital.

Growth Hormones

The seeming simplicity of plants some times leaves us unprepared for their complexities. As a case in point, researches have for many years been trying to unravel the mysteries of plant hormonal control. Many aspects of plant growth and development are under the control of these chemicals. Let's briefly consider three of the better known groups of plant hormones; **auxins**, **gibberellins** and **cytokinins**.

Auxins

Some of the first experiments on plant hormones were conducted by one Charles Darwin and his son, Francis, and reported in an 1881 publication entitled, "The power of movement in plants". After noticing that plants tend to bend towards light, they covered the shoot tip of growing plants and exposed it to light from the side. Nothing happened, the plants continued to grow straight up. If the tips were capped with transparent glass, however, normal bending occurred. They stated, "we must therefore, conclude that when seedlings are freely exposed to a lateral light some influence is transmitted from the upper to the lower part, causing the latter to bend".

In 1926, the Dutch physiologist, Frits, W. Went, discovered something else about that "influence". He cut off the tips of emerging oat seedlings and set them on a block of gelatinous agar for about an hour. The decapitated plants were kept in a dark place. Then they were removed and pieces of the agar on which the tips had rested were placed along one side of the stump. Within an hour the plant began bending in the opposite direction. Thus the influence was believed to be chemical and was called auxin (from the Greek auxin, to increase). It was later found that auxin is generally, produced in the stem tips and seeps through the cell tissue to the rest of the plant, instead of travelling in pipelines of xylem and phloem. But how does 'auxin control elongation in plants? It is known that auxin softens the rigid cell walls of plants and allows water to swell the cells. Thus growth may be accomplished by cell enlargement rather than cell division (Fig. 13.7).

The only naturally occurring auxin is indole-acetic acid, or IAA, but a synthetic form, 2,4-D (2,4-dichlorophenoxy acetic acid), is powerful weedkiller (as is auxin at high concentrations) and was used by the military in South East Asia.

Small amounts of auxin may stimulate the growth of roots, and although it does not affect the growth of leaves, it plays a role in the leaf drop. With the approach of

fall, the plant draws certain ions, amino acids and sugars from its leaves and auxin helps to break down the cells that hold the leaf to the stem. Auxin also can stimulate fruit to grow without having ever been pollinated, thus producing seedless varieties.

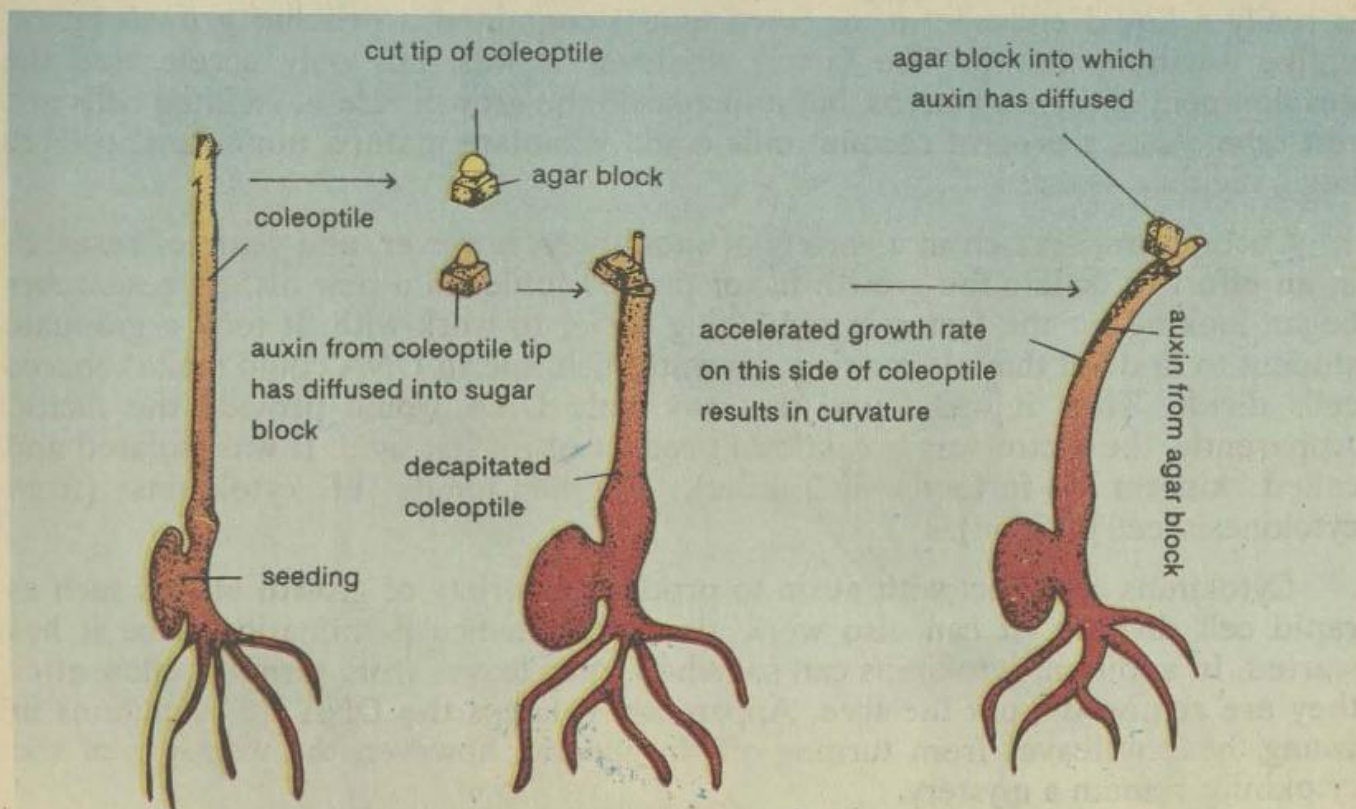


Fig. 13.7 In this classical experiment, the tip was cut from an oat seedling and placed on an agar cube to absorb any juices, including hormones, from the tip. Then the block was placed on centre off a decapitated seedlings. As the seedlings grew it bent away from the side with the agar block, demonstrating the growth inducing properties of plant hormones.

Gibberellins

While Went was performing his agar experiments, E. Kurosawa (1926) in Japan was looking for the cause of the "foolish seedling disease" of rice. The disease caused the plants to become spindly and pale and to simply collapse. It turned out that the culprit was a parasitic fungus that contained a substance called **gibberellin**.

Gibberellins are found in most, if not all plants and they have some rather surprising traits. For example, they cause dramatic increases in stem length by stimulating cell division and cell elongation in both leaves and stems. Gibberellins stimulate pollen germination and the growth of pollen tubes in a number of plant

genera, and can break the dormancy of many kinds of seeds that normally can be aroused by nothing but cold or light.

Cytokinins

In 1941, a Dutch physiologist, J. Van Overbeek found that coconut milk (which is really a liquid endosperm, or "seed food") contained a peculiar growth factor, unlike anything known. The factor, whatever it was, not only accelerated the development of plant embryos, but it increased the growth rate of isolated cells in a test tube. Also, a drop of coconut milk could stimulate mature, nonmitotic cells to begin dividing again.

Coconut milk is rich in a variety of substances, however, and years of research in an effort to isolate the growth factor proved futile. In a new attack, researcher began looking for the factor in something easier to work with. It took a graduate student to find out that old herring, sea water fish, sperm DNA could make tobacco cells divide. Then it was found that any stale DNA would provide the factor. Apparently, the factor was breakdown product of nucleic acid. It was isolated and called **kinetin** (6-furfurylaminopurine), of the family of cytokinins (from cytokinesis, cell division).

Cytokinins can react with auxin to produce a variety of growth effects such as rapid cell division. It can also work alone to enhance germination once it has started. In addition, cytokinins can somehow keep leaves from turning yellow after they are removed from the tree. Apparently it keeps the DNA that functions in young, healthy leaves from turning off. In general, however, the workings of the cytokinins remain a mystery.

Growth Correlations

The development of every organ of a growing plant is influenced to some degree by the physiological processes or physiochemical conditions prevailing in some other organ or organs. Thus the vegetative growth of many plants is sharply checked during the period of fruiting because the presence of developing fruits strongly influences processes occurring in the root system. Similarly, the size and vigour of root systems are influenced by photosynthetic activities of the leaves, and the formation of flower buds and flowers may be controlled by processes taking place in leaves. Such relationships often reciprocal, existing among the organs of a plant, are termed **growth correlations** or often simply **correlations**.

Growth correlations are not only exerted by one organ on another but also occur among tissues and even among cells. The harmonious development of the plant body as a whole is a result of correlative influence operating from organ to organ, tissue to tissue and cell to cell. The discussion in this chapter will be restricted almost entirely, however, to some of the better known examples of the correlative influences of one plant organs or another.

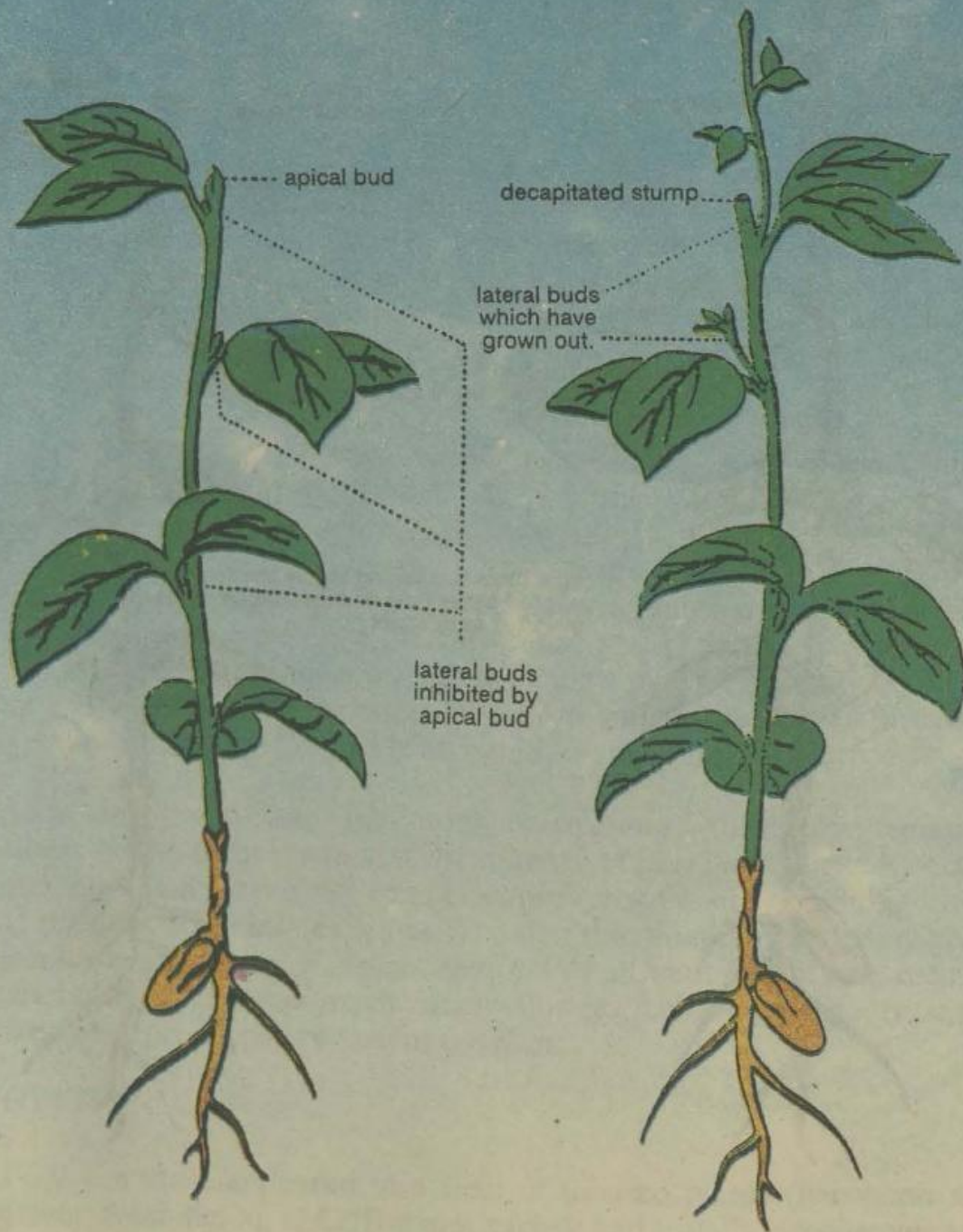


Fig.13.8(a) Removal of the apical bud permits the inactive lateral buds to grow out.

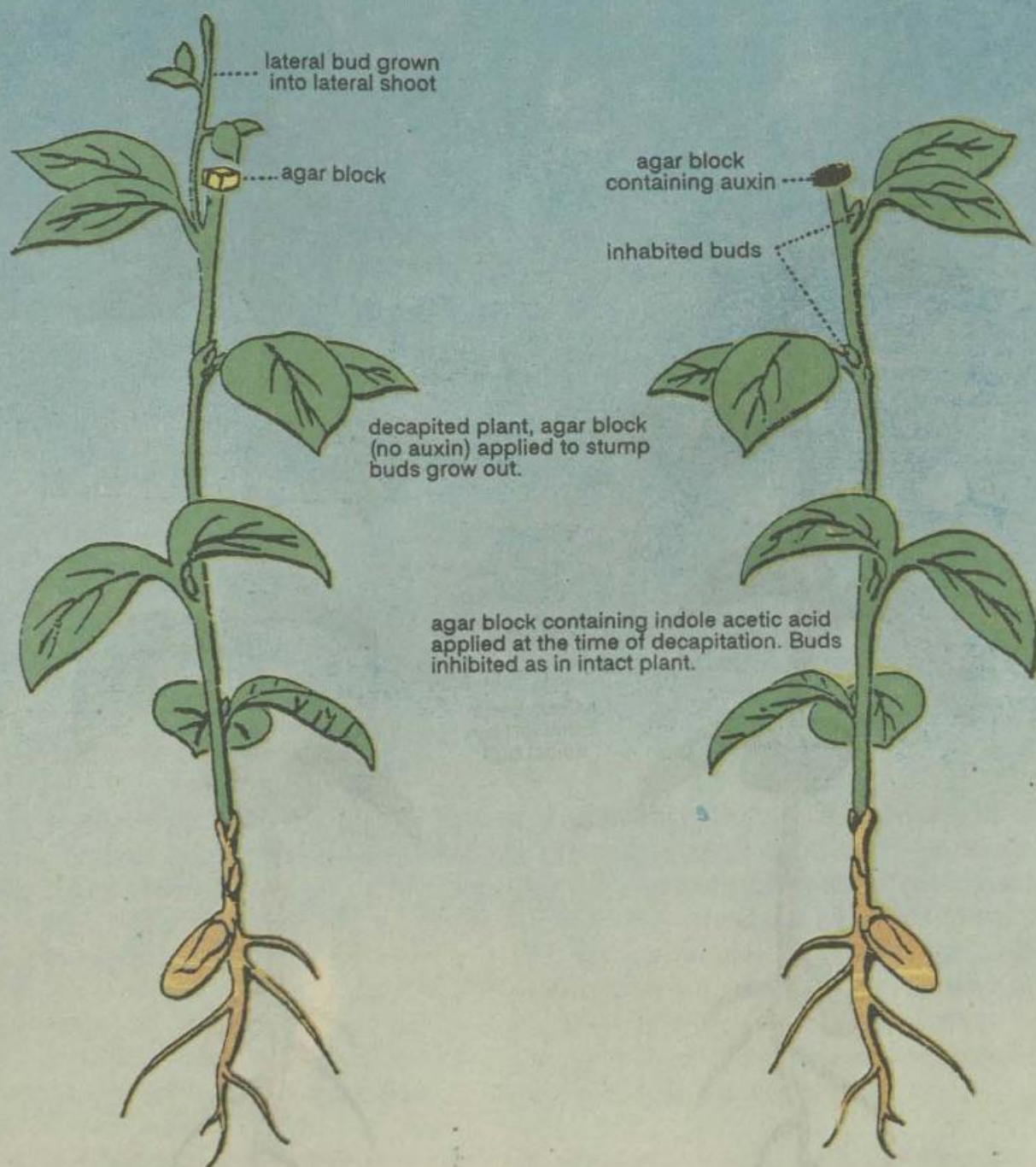


Fig.13.8(b) The growth of lateral buds after removal of the apical bud is inhibited by the application of auxin to the surface of the stem.

Apical Dominance: (Inhibitory Correlation)

Apical dominance is one of the most familiar and indeed the most important example of correlation in plants. The active shoot apex controls the development of lateral buds. This control or regulation of branch formation and development has profound effects on the overall appearance of the plant e.g., a simple main shoot or a much branched shrubby appearance.

There is a great deal of variability between species with respect to the degree of dominance. In some tall varieties of sunflower the dominance is complete. In others such as tomato the dominance of the apical bud is weaker and the axillary buds situated just below the main stem tip grown out resulting in a bushy structure. In many species the dominance becomes weaker as the plant gets older. If the shoot is decapitated i.e., the apical bud is cut off then one or more of the lower axillary buds grow out. Usually one of the out growing laterals become dominant and exerts an inhibitory effect on the buds below (Fig. 13.8).

Thimann and Skoog in 1934 found that exogenous IAA could substitute for the apical bud in maintaining inhibition. This observation has been confirmed for several species with few exceptions. The way in which auxin causes inhibition of axillary buds is not fully understood. It appears strange that auxin which is considered as a promoter of growth, should cause an inhibition of growth in axillary buds. Several theories have been put forwarded to explain this. However, research over the past decade has indicated that cytokinins play an important role in apical dominance. In many plants application of cytokinins directly on the correlative inhibited bud, can release the bud from inhibition in an intact plant.

Besides nutritional and inhibitory correlations, there are **compensatory correlations**. In the higher plants, if the number of parts is reduced by accident or experimentally then there is compensatory growth of remaining structures. Thinning of fruits is sometimes practical so that the remaining fruit may grow large. In the same way, in *Chrysanthemum* removal of all buds except one results in the development of single and much larger flower. A balance also occurs in the vegetative and reproductive phases of the plant.

PHOTOPERIODISM

In 1920 a mutant appeared in a field of tobacco plants (*Nicotiana tabacum*) growing near Washington, D.C. The new variety had usually large leaves and stood over 3 meters tall. As the season progressed, the regular plants, flowered, but Maryland Mammoth, as it came to be known just grew bigger and bigger. Investigators from the department of agriculture. W.W. Garner and H.A. Allard, took cuttings from the Mammoth and put them in the green house, where it would be safe from frost. These cuttings flowered in December, although by then they

were only 1.5 metres tall, the size of their parent. New Maryland Mammoths grew from their seed, and these, too, did not flower until almost winter.

Coincidentally, Garner and Allard were carrying out experiments with the biloxi variety of soybean (*Glycine max*). Agriculturalists were interested in spacing out the soybean harvest by making successive sowings of seeds at two-weeks intervals from early May through June. But spacing out the planting had no effect, all the plants no matter when the seeds were sown, came into flower at the same time in September.

The investigators growing these two kinds of plants Maryland Mammoth tobacco and biloxi soybeans under a wide variety of controlled conditions of temperature, moisture, nutrition, and light. They eventually found that the critical factor in both species was the length of day. Neither plant would flower unless the day length was shorter than a critical number of hours consequently, soybeans, no matter when they were planted, all flowered as soon as the days became short enough, which was in September, and the Maryland Mammoth, no matter how tall it grew, would not flower until December, when the days had become even shorter.

Garner and Allard called this phenomenon **Photoperiodism**. Photoperiodism is a biological response to a change in the proportions of light and dark in a 24-hours daily cycle.

Photoperiod Responses

We recognize today that plant fall into three broad photoperiodic classes with respect to their flowering behaviours.

1. Short - day Plants:- Which flower when the day length is below some critical value, usually in spring or fall. Some examples of short-day flowering plants are *Xanthium pennsylvanicum* (cocklebur), *Nicotiana tabacum* var. Maryland Mammoth (tobacco), *Chrysanthemum indicum* var. Queen Mary (Gul-e-daudi), *Euphorbia pulcherrima* (poinsettia) and *Glycine max* (biloxi soybean).

2. Long - day Plants:- Which bloom when the day length exceeds some critical value usually in summer. Some examples of long-day plants are *Hyoscyamus niger* (henbane) *Spinacea oleracea* (spinach), *Beta vulgaris* (sugar beet) *Delphinium ajacis* larkspur), and *Anethum graveolens* (dill).

3. Day - neutral Plants:- Which are independent of day length and can bloom under conditions of either longer or short days. Some examples of day neutral plants are *Zea mays* (corn), *Lycopersicum esculentum* (tomato), *Viola tricolor* (pansy) *Helianthus annuus* (sunflower) and *Cucumis sativus* (cucumber).

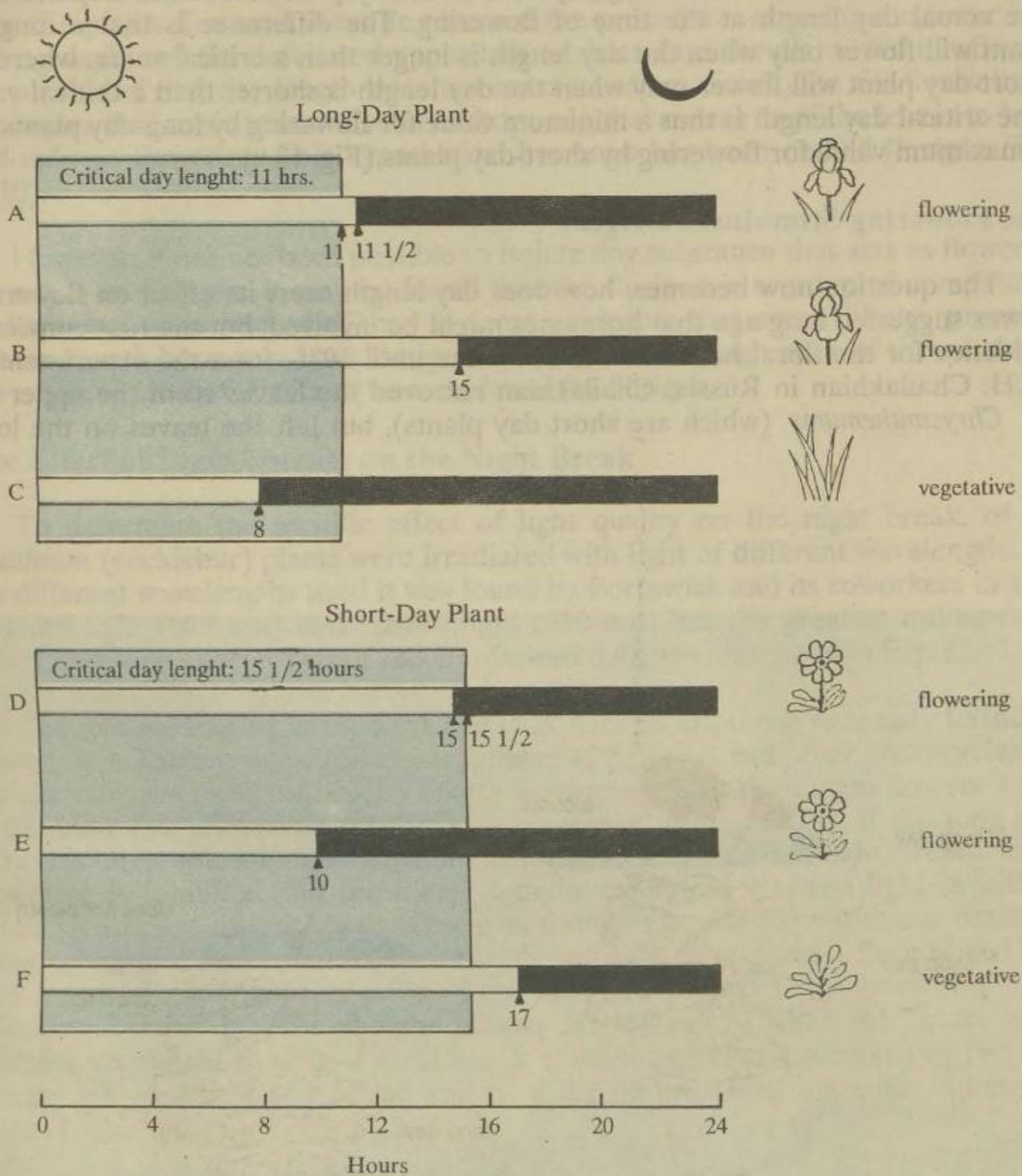


Fig. 13.9. Comparison of hypothetical long-day and short-day plants. The difference is that the critical day length is minimum value for the long day plant and maximum value for the short day plant. Thus the long day plant will flower when the day length is slightly above the critical value (A) or when it is much above the critical value (B). But will not flower when it is below the critical value (C). Conversely, the short day plant will flower when the day length is slightly below the critical value (D) or when it is much below the critical value (E), but will not flower when it is above the critical value (F).

The difference between long-day and short-day plants does not depend upon the actual day length at the time of flowering. The difference is that a long-day plant will flower only when the day length is longer than a critical value, whereas a short-day plant will flower only when the day length is shorter than a critical value. The critical day length is thus a minimum value for flowering by long-day plants and a maximum value for flowering by short-day plants (Fig. 13.9).

The Flowering Stimulus: Florigen:

The question now becomes: how does day length exert its effect on flowering? It was suggested long ago that hormones might be involved, but the first convincing evidence for the floral hormone did not come until 1936, from the experiments of M.H. Chailakhian in Russia. Chailakhian removed the leaves from the upper half of *Chrysanthemums* (which are short day plants), but left the leaves on the lower

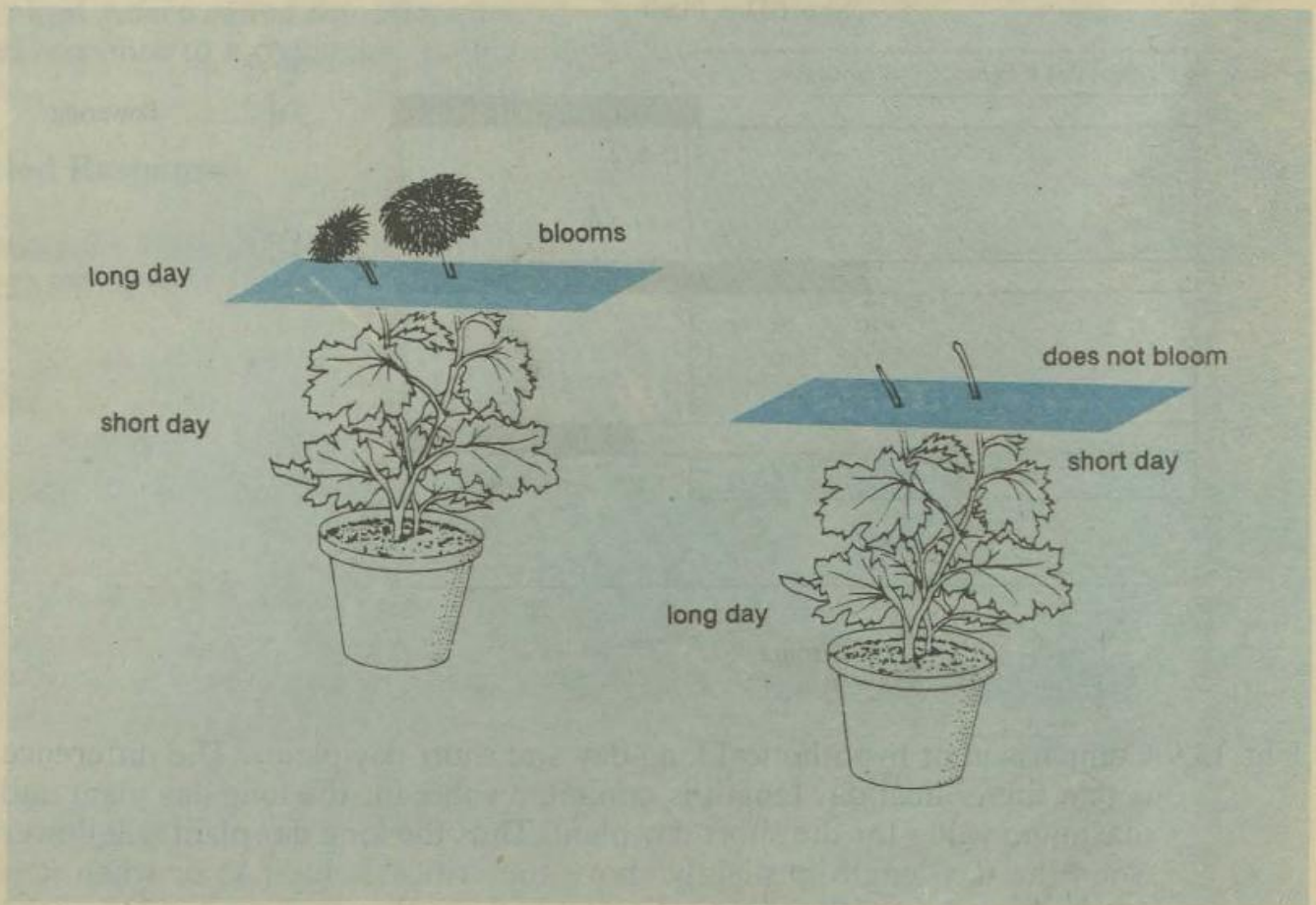


Fig. 13.10 Chailakhians experiment on short-day plant *Chrysanthemum*.

half to short days while simultaneously exposing the defoliated upper half to long days, the plants flowered. Next he reversed the procedure, exposing the lower half to long day's and the defoliated upper half to short days the plants did not flower. He concluded that day length does not exert its effect directly on the flower buds, but causes the leaves to manufacture a hormone that moves from the leaves to buds and induces flowering. This hypothetical hormone has been named **florigen** (Fig. 13.10).

However, it has not been possible to isolate any substance that acts as flowering hormone, or florigen. It may be found that the florigen is a group of compounds, perhaps not even related. There is some evidence, that some of the presently known growth hormones have florigenic properties, although none of them have all the required characteristics to be considered the florigen.

The Effect of Light Quality on the Night Break

To determine the specific effect of light quality on the night break, of the *Xanthium* (cocklebur) plants were irradiated with light of different wavelengths. Of the different wavelengths used it was found by Borthwick and its coworkers in 1952 that red light (660 nm) and far-red light (730 nm) has the greatest influence on flower initiation. The effects of red and far-red light are illustrated in Fig. 13.11.

The relative lengths of the light and dark periods are those necessary to induce flowering in *Xanthium* (critical day lengths of 15.5 hours), but other photocycles are equally effective if the critical day length is achieved. *Xanthium* plant flowers with a single inductive photocycle (9L/15D), as shown in treatment (a). If the long dark period is interrupted with either white light (treatment b) or red light (treatment c), flowering is inhibited and the plants remain vegetative. Far-red light is without effect (treatment d), the plants behave as though exposed to continuous darkness, (treatment a). When a flash of far-red light immediately follows a flash of red light (treatment e), the inhibitory effect of red light (treatment c) is negated and flower initiation occurs. When red light follows far-red light (treatment f), the plant remains vegetative as after a night break of white light (treatment, b) or red light (treatment, c). The effect of red and far-red light on flower initiation in long-day plants is also illustrated in Fig 13.11.

Recall that long-day plants set flowers when the photocycle is longer than the critical day lengths and that flowering is inhibited by long, uninterrupted dark periods. Under a photoperiod of 9L/15D a long-day plant such as *Hyoscyamus* (henbane, critical day length of 11 hours), remain vegetative (treatment, a). If the long dark period is interrupted by white light or red light (treatments, b and c) flowering is initiated. Far-red light (treatment d) is without effect and the plants remain vegetative. However, red and far-red light interact (treatments, e and f) with the flowering pattern depending on the wavelength last perceived.

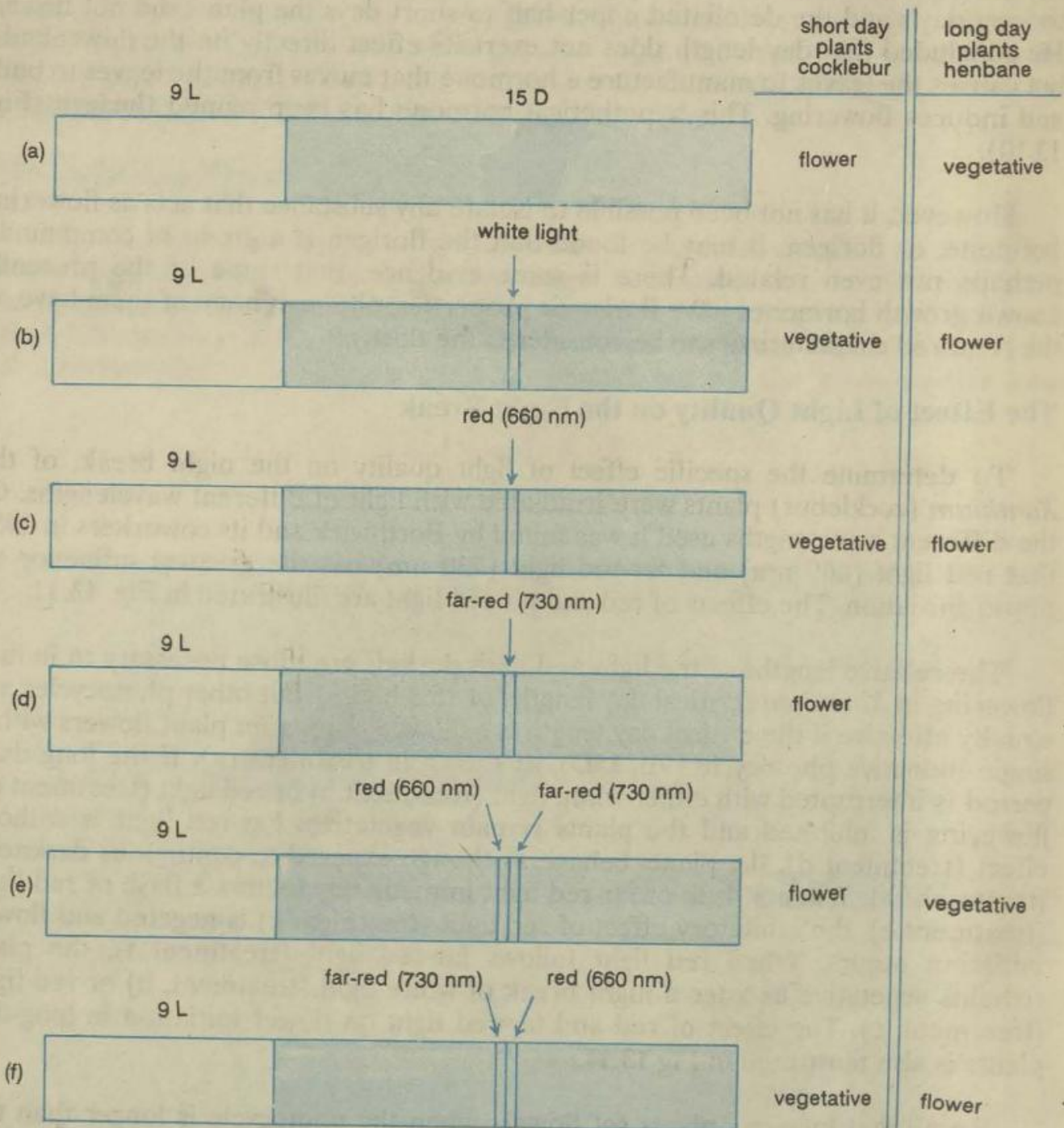


Fig. 13.11 The effect of red and far-red light during a night break on the flowering of short and long-day plants. Light during the major light period is either sunlight or high intensity radiation from incandescent lamp.

The reversible action of red and far-red light on flower initiation established that a pigment phytochrome is involved, the same pigment is involved in seed germination and other photomorphogenetic responses.

The Role of Phytochrome in Flower Initiation

The precise role of phytochrome in flower initiation is not known. Phytochrome is not the flowering stimulus, but it is involved in triggering the formation (synthesis

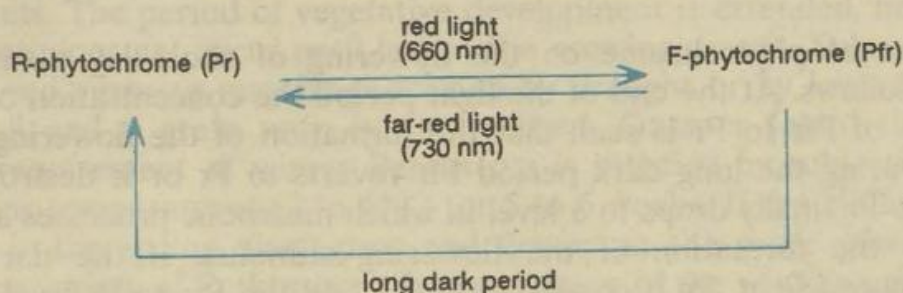


Fig. 13.12a Pr changes to Pfr. When exposed to red light. Pfr reverts to Pr when exposed to far-red light. In darkness, Pfr reverts to Pr.

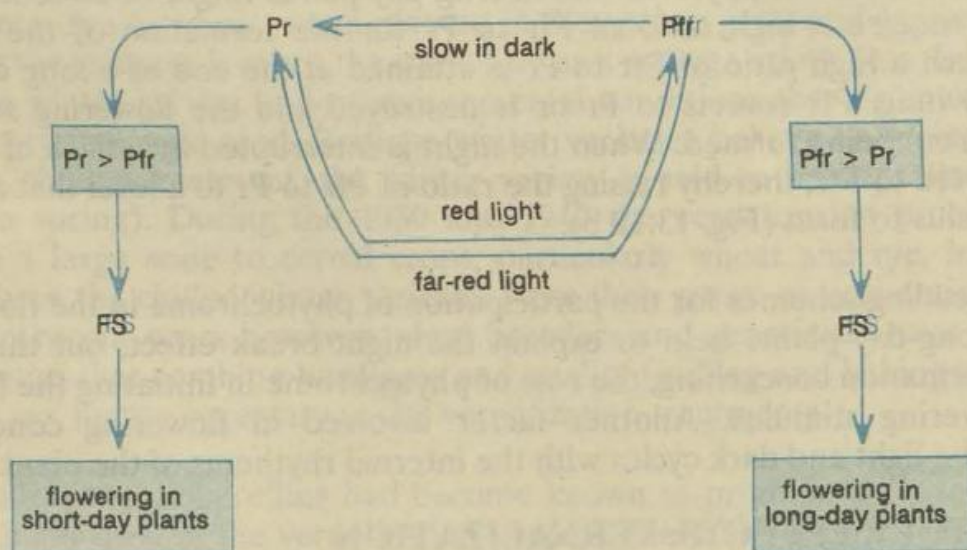


Fig 13.12b The possible participation of phytochrome in the flowering response of short-day and long-day plants. Pfr-far red absorbing form of phytochrome. Pr-red absorbing form of phytochrome. FS-Flowering stimulus (Florigen).

or activation) of the flowering stimulus. The phytochrome exists in two different forms, red light absorbing form (Pr) and far-red light absorbing form (Pfr). These two forms of the pigment are photochemically interconvertable. When Pr form absorbs red light (660 nm), it is converted into Pfr form. When Pfr form absorbs far-red light (730 nm) it is converted into Pr form in dark. the level of phytochrome Pfr, the physiologically active form, depends on a number of factors, for example temperature, photoperiods and growth substances (Fig. 13.12 a).

Short-Day Plants

The effect of phytochrome on the flowering of short-day plants might be imagined as follows. At the end of the light period the concentration of Pfr is high and the ratio of Pfr to Pr is such that the formation of the flowering stimulus is prevented. During the long dark period Pfr reverts to Pr or is destroyed and the ratio of Pfr to Pr finally drops to a level in which metabolic processes are triggered that lead to the formation of the flowering stimulus. If the dark period is interrupted by red light, Pr is converted to Pfr and the Pfr to Pr level is such that the formation of the flower stimulus is prevented (Fig. 13.12 b).

Long-Day Plants

The possible role of phytochrome in long-day plants might be as follows. Long-day plants require a high ratio of Pfr to Pr for the formation of the flowering stimulus. Such a high ratio of Pfr to Pr is attained at the end of a long day. If the night is too long, Pfr reverts to Pr or is destroyed and the flowering stimulus is prevented from being formed. When the night is interrupted by a flash of red light, Pr is converted to Pfr, thereby raising the ratio of Pfr to Pr to a level that allows the flower stimulus to form (Fig. 13.12 b).

The preceding schemes for the participation of phytochrome in the flowering of short and long-day plants help to explain the night break effect, but they do not provide information concerning, the role of phytochrome in initiating the formation of the flowering stimulus. Another factor involved in flowering concerns the phasing of the light and dark cycles with the internal rhythms of the plant.

TEMPERATURE EFFECTS: VERNALIZATION

Agronomists, horticulturists, and gardeners long recognized a relationship between temperature and flowering, but it remained for C. Gassner in 1918 to point out that temperature was especially critical during early stages of seed germination. Furthermore, the presence or absence of appropriate temperatures during this critical stage determines the success or failure of flowering and fruiting. Gassner's studies were carried out on rye (*Secale cereale*, Cv. Petkus). In Petkus rye, as in a number of other cereals grown in temperate regions, there are two varieties, winter and spring. Winter Petkus rye is sown in the field in the fall of the

year, where it germinates and sends up a few leaves. Further growth is checked for several months by low winter temperatures. In many instances the plants are covered by snow. When the temperature moderates in the spring, the plants resume growth, flower, and produce a grain crop during the summer. Spring Petkus rye, on the other hand, is sown in the spring, at which time it germinates and immediately proceeds through vegetative and reproductive growth to give a grain crop that is harvested in the summer.

If winter rye is planted in the spring, the seeds germinate and produce vegetative plants. The period of vegetative development is extended, however, and flower initiation does not occur until late in the growing season. Subsequent grain development and ripening may be prevented by drought or by low temperatures during the fall and a grain crop is not realized. Gassner found that the low temperature requirement of winter Petkus rye is satisfied by subjecting imbibed seeds to chilling temperatures (2 to 5°C) for 5 to 6 weeks. If the chilled seeds are then planted in the spring, they grow and flower on the same schedule as the ordinary spring variety of Petkus rye. The conversion of the winter variety into the spring variety by low temperature or chilling treatment was termed as **vernalization** by Lysenko (1928).

The practical significance of Gassner's observation on the chilling requirements of winter Petkus rye did not go unnoticed by agriculture workers. Chilled, imbibed seeds of winter rye or wheat, when planted in the spring, grow and produce a grain crop during the summer in much the same way as a spring variety. It is thus possible to grow the winter variety under environmental conditions that ordinarily do not allow it to produce ripe seed. Because winter varieties behave as spring varieties following a chilling treatment, the winter variety is said to be vernalized (vernal referring to spring). During the 1930 and 1940 the vernalization procedure was applied on a large scale to cereal crops, particularly wheat and rye, in northern Europe, where the chilled winter varieties were then grown as conventional spring varieties. In recent years however, plant breeders and geneticists have developed cereal varieties that combine hardiness and quality (milling and baking properties) so that it is no longer necessary to use vernalization treatments.

Later, after the gibberellins had become known as prominent phytohormones, they were implicated in the vernalization process. There are several biennials, such as henbane that can be made to flower in the first season by the application of gibberellin alone. Some scientists considered that the **vernalin** produced after cold treatment and gibberellin to be one and the same, which show similar effect on flowering during vernalization.

APOMIXIS

Any form of asexual reproduction including vegetative propagation is termed as **apomixis**. Wrinkler (1908) coined this term and defined it as a process of asexual

reproduction during which there is no nuclear fusion of the male and female gametes. The term is very often used in a narrower sense to mean the production of seeds without the occurrence of fertilization. In this restricted sense the terms is synonymous with agamospermy. Seed production by apomixis may occur either: (1) by the formation of diploid embryo or embryo sac by a somatic cell, (2) or by suppression or modification of the meiotic process to give unreduced megaspores. Development into a mature diploid embryo can then proceed without fertilization, that is by **parthenogenesis**.

Apomixis is usually associated with polyploidy. An organism that reproduces by apomixis is termed as **apomict**. **Facultative apomicts**, e.g., the cinquefoiles (potentilla), can reproduce both sexually and apomictically. In such species, the incidence of apomixis may be affected by environmental factors, such as photoperiod. **Obligate apomicts** can only reproduce apomictically. Often these are triploids or pentaploids that cannot produce viable pollen. Some apomictic races are so constant that they have been given taxonomic status as species e.g., almost 400 species of *Rubus* have been recognized in Britain.

PLANT MOVEMENTS

Plant movements, are usually too slow for direct observation but the results are easily noticed. The opening and closing of flowers, the unfolding of buds, the bending towards light, and the twining of tendrils are examples of movements. The use of time lapse photography has made it possible to observe such movements in considerable detail. As a result of these and other investigations, plant movements have been classified in various ways, but all such classifications are simply an aid to understanding. There are overlaps and not all movements fit neatly into the given categories.

In general, movements of plant parts can be classified, according to the mechanism involved, **turgor movements** or **growth movements**. Turgor movements are due to differential changes in turgor and size of the cells as a result of the gain or loss of water, and are easily reversible. Growth movements are irreversible and due to differential growth rates of cells in different parts of the affected organs.

1. Turgor Movements

The effective cells are often different from ordinary cells and may be concentrated in certain areas. The rolling of leaves of many grasses in dry weather is caused by loss of water of the bulliform cells, which form longitudinal rows in the epidermis. The drooping and folding up at night (sleep movements) in some plants are caused by turgor changes in the cells of the pulvinus at the base of the leaf or leaflet. The pulvinus is a thickened portion of the petiole, composed primarily of parenchyma cells with relatively large intercellular spaces and a central strand of

vascular tissue. Water passes into or out of the cells more freely on one side of the pulvinus than on the other. This unequal movement of water causes unequal enlargement or shrinkage (turgor responses), and a consequent movement of the petiole and blade. The drooping of leaves or leaflets of the sensitive plant (*Mimosa pudica*) when touched results from differential changes in turgor of the cells in the pulvini. The mechanism bringing about such turgor changes have not yet been clarified.

2. Growth Movements

Growth movements may be spontaneous and self controlled, **autonomic** or they may be induced by external stimuli - **paratonic**. The paratonic may be further classified as tropisms and nastic movements. **Tropisms** are responses to stimuli that come chiefly or wholly from one direction. **Nastic** movements are responses that are independent of the direction from which the stimulus is received, the stimulus may be uniform or nondirectional.

(A) Autonomic Movements

The growing tip of a young stem sometimes moves slowly in a zigzag manner, due to the alternate changing in growth rate on opposite side of the apex. This mode of growth is usually termed **nutation** and is common in those stem apices which are not strictly rounded, but slightly flattened. The nutation of twining vines is more prominent, when a solid object is touched. A nutational movement may be called **circumnutation**, when strictly rounded apices make rotational growth around its long axis.

(B) Paratonic Movements

(i) Tropisms

It is classified into **geotropism** and **phototropism**. Plants may grow up (negative geotropism-opposite to the direction of gravitational pull) or down (positive geotropism). However, leaves as well as stems are often phototropic. In many instances, the petioles of leaves bend in such a way that the blades are oriented at right angles to the source of illumination with a minimum of overlapping, fitting into patterns termed **leaf mosaics**. Such an arrangement results in little shading and a maximum use of available light.

(a) Thigmotropism: is a growth movement in response to contact with a solid object and is most readily apparent in tendrils of climbing vines. The immediate reaction is probably due to turgor changes, but this is followed by increased growth on the side apposite to the point of contact so that the tendril coils around the supporting object. Tendrils do not respond to liquids, not even to heavy liquids such as

mercury; nor do they respond to perfectly smooth solids. A rough or uneven surface is required for reasons that are not clear.

(b) **Chemotropism**: is a response to chemicals. The growth of the pollen tube through the style to the ovule and the bending of *Drosera* "tentacles" around the insect are example. The latter movements is partly thigmotropic, but the continuous chemical stimulus of a trapped insect causes the tentacles to remain curved; recovery, within a day occurs if the object is not digestible.

(ii) Nastic Movements

The growth movements of bud scales, young leaves, and petals are examples of nastic movements. These organs grow faster on the lower side when young, resulting in an upward and inward bending, which encloses the tip of the axis. The unfolding of the bud occurs later when growth is more rapid on the upper surface. The principal stimuli appear to be the photoperiod or temperature to which the bud is exposed. Some investigations indicated that these growth changes may be due to some balance or ratio between growth inhibitors (abscisins) and growth stimulators (gibberellins). Sleep movements of some plants are growth responses rather than turgor movements. Fluctuations of light and temperature produce nastic movements in many flowers. Tulip and dandelion (*Taraxacum*) flowers tend to be open during the day but close at night, while some species of *Oenothera* (evening primrose) open in the evening.

The closure of leaves of *Dionaea muscipula* is a rapid turgor response followed by a differential growth response, which may be considered to be a combination of thigmonasty and chemonasty. Closure may be brought about by touch, but continued closure depends upon further chemical stimulation with nitrogenous substances from the insect body.

QUESTIONS

1. How respiration and photosynthesis are similar with each other and how are they different?
2. What are different kinds of respiration? Why respiration is needed in living organisms?
3. Discuss in detail the process of Glycolysis.
4. Describe the steps that occur during Krebs's cycle.
5. What do you mean by growth? Where growth occurs in plants?
6. What are growth hormones? What is their role in plants?

7. Define photoperiodism. What is its mechanism?
8. Explain vernalization and point out its importance in agriculture.
9. Write short note on apomixis.
10. What is tropism, discuss its kinds?
11. Describe the turgor and nastic movements.

GLOSSARY

A

absorption: The passage of material across a cell membrane into the cell; the process by which usable materials are taken into an organism.

absorption spectrum: A plot of absorbence of light versus wavelength.

action spectrum: A plot of effectiveness of light in initiating a particular response verses the wavelength.

active transport: A process in which the movement of materials across a cell membrane requires the expenditure of cell energy.

active site: The region on an enzyme where the reaction it catalyzes takes place.

adaptation: An inherited trait or modification that improves the chance of survival and reproduction of an organism in a given environment.

adenine: A nitrogenous base found in DNA and RNA.

ADP (adenosine diphosphate): The low energy compound remaining after one phosphate group is removed from ATP.

aerobic respiration: Respiration requiring the presence of free oxygen in which glucose is completely oxidized to carbon dioxide and water.

alternation of generation: A life cycle of some plants that involves a multicellular monoploid generation alternating with a multicellular diploid generation.

amino acid: The structural unit of proteins; contains a carboxyl group ($-COOH$), an amino group ($-NH_2$) and a side chain.

amino group: A chemical group composed of two hydrogen atoms and one nitrogen atom, found in amino acids.

amphibia: A class of land and water dwelling vertebrates having moist, smooth, scaleless skin and four limbs; they need water for reproduction; amphibians.

anaerobic respiration: Respiration in the absence of free oxygen, in which glucose is partially oxidized.

anal pore: The opening through which indigestible wastes are ejected from a paramecium.

anaphase: The stage of mitosis during which the daughter chromosomes move to opposite poles.

anemia: A disorder in which the blood contains few red blood cells or insufficient haemoglobin.

angiosperm: A flowering plant.

animalia: One kingdom of living things; comprises of multicellular usually motile, heterotrophic organism; animals.

anther: The saclike structure of a stamen in which pollen grains are produced.

apical dominance: Suppression of growth of lateral buds as a result of auxin production by terminal bud.

apomixis: A collective term for absence of sexual union and failure of meiosis.

ascomycetes: A group of fungi; sac fungi.

asexual reproduction: A type of reproduction in which there is only one parent; all offsprings are genetically identical to parents.

assimilation: The incorporation of materials into the body of an organism.

aster: A star shaped structure formed during mitosis or meiosis in animal cells by fibers extending from the centriole.

ATP: (adenosine triphosphate): The compound in which energy released by cellular respiration is stored.

autonomic movements: It refers to movements resulting from internal stimuli e.g., mutation.

autotroph: An organism capable of synthesizing its needed organic nutrients from inorganic substances.

auxin: A hormone that affects the growth of all types of plant tissues.

B

bacillus: A rod shaped bacterium, bacteriophage. A virus that infects bacteria; phage virus.

bark: The protective, outermost layer of a woody stem or root.

bilateral symmetry: A type of symmetry in which there is only one longitudinal section that will divide the organism into two parts that are mirror images of each other.

binary fission: The simplest form of asexual reproduction, in which a unicellular parent organism divides into two approximately equal cells.

binomial nomenclature: The two - word system that identifies each kind of organism by use of its genus and species name.

bivalent chromosomes: Pair of homologous chromosome, side by side during meiosis (zygotene).

bivalve: A member of class which includes clams, oysters, mussels etc., a mollusk having a two part shell.

blade: The thin flat extended part of a leaf.

Bryophyta: A phylum of land plants lacking vascular tissues; they grow in moist places.

budding: A type of asexual reproduction in which the parent organism divides into two unequal parts.

C

calyx: The complete circle of sepals in a flower.

cambium: A lateral meristem in woody plants that produces secondary xylem and phloem (vascular cambium).

capitulum: Type of inflorescence consisting of a flattened axis bearing close packed sessile flowers.

carbon fixation: The process in which carbon dioxide is incorporated into organic compounds by the process of photosynthesis and chemosynthesis.

carnivora: An animal that feeds on other animal; order carnivora.

catalyst: A substance that increases the rate of a particular chemical reaction without being changed itself.

catkin: Type of inflorescence consisting of a spike of unisexual reduced flowers.

- cell membrane:** The structure that separates the interior of a cell from the surrounding environments and controls the passage of materials into and out of cell; plasma membrane.
- cellular respiration:** The process by which energy stored in food is released by cells.
- cellulose:** Carbohydrate which is a basic structural material of the cell wall in green plants.
- cell wall:** The rigid structure, often composed of polysaccharides that encloses the cells of plants and various microorganisms.
- centriole:** A cylindrical organelle found near the nucleus in animal cells that is involved in mitosis.
- centromere:** The region of attachment of two sister chromatids.
- chemosynthesis:** A form of autotrophic nutrition in which energy for synthesizing organic compounds is obtained from inorganic compounds rather than from light.
- chemotropism:** Response by plants to chemical stimulus resulting in growth curvature in a direction determined by the site of the stimulus.
- chiasmata:** Interchange at corresponding points between paired chromatids of homologous chromosomes.
- chitin:** The polysaccharide that makes up the exoskeleton of arthropods.
- chlorenchyma:** Parenchyma containing chloroplasts.
- chlorophyll:** The major photosynthetic pigment of plants and algae.
- chloroplast:** A plastid that contains chlorophyll and is the site of photosynthesis in eukaryotic cell.
- cholesterol:** A steroid found in animal cells; play a role in the buildup of fatty deposits in arteries.
- chordata:** A phylum of animals having at some stage of development a notochord paired gill slits, and a dorsal hollow nerve chord; chordates.
- chromosome:** A thread-like or rod-like body which is present in the nucleus of eukaryotic cell.
- chromatid:** One of the two strands of a doubled chromosome.
- chromatin:** The material of which chromosomes are composed.
- chromoplast:** A plastid that contains pigments other than chlorophyll.
- cilium:** (pl. Cilia): A short hair like organelle at the surface of a cell with the capacity of movement.
- cleavage:** In a fertilized egg, the first series of cell divisions.
- club moss:** Small spore producing tracheophytes with true roots, stems and leaves.
- coelom:** The fluid-filled body cavity between the body wall and the digestive tube.
- coenzyme:** A non protein organic substance necessary to the functioning of a particular enzyme.
- cohesion:** Tendency of particles or substance to stick together
- collar cell:** A type of flagellated cells found in the inner layer of a sponge.
- concentration gradient:** The difference in concentration between a region of greater concentration

cone: A structure in the retina of the eye responsible for colour vision. In gymnosperms the seed bearing, or pollen bearing structure.

conifer: Cone bearing seed plants with needle like or scale like leaves.

conjugation: A form of sexual reproduction found in protists; the individual organisms appear to be identical but are of different mating types.

consumer: A heterotroph; an organism that obtains nutrition from other organisms.

controlled experiment: An experiment set up in duplicate with a single factor changed in one of the set up.

corm: A short, vertical underground stem containing stored food, it can give rise to new plants by vegetative reproduction.

corolla: The complete circle of petals in a flower.

cortex: The outer region or layer of a plant or animal organ or structure.

corymb: Type of inflorescence consisting of a raceme in which the stalks of lower flower are elongated, all the flowers being borne at or near the same level.

crossing over: The process in which pieces of homologous chromosomes are exchanged during synapsis in the first meiotic division.

cuticle: The layer of cutin that covers the plant epidermis.

cutting: Any vegetative part of a plant used to produce a new plant by artificial vegetative reproduction.

cymose: Type of inflorescence in which the main axis ends in a flower, further development taking place by growth of lateral branches which also end in flower.

cytokinin: A plant hormone that stimulates cell division and growth.

cytoplasm: The watery material between the nucleus and the cell membrane of a cell.

cytosine: A nitrogenous base found in DNA and RNA

D

dark reaction: The series of reactions in photosynthesis in which carbon fixation occurs and which do not require light.

diploid: having two of each type of chromosomes.

DNA (deoxyribonucleic acid): The nucleic acid that contains the hereditary information.

dormancy: A period during which growth and other metabolic activities stop or are severely reduced.

E

echinodermata: A phylum of marine animals having a water vascular system, and internal skeleton, and a spiny skin, echinoderms.

ecology: The branch of biology that deals with all the interactions between organisms and their environment.

ectoderm: The outer layer of cells in a simple animal or embryo, one of the germ layers of an animal embryo.

ectothermic: Having a body temperature that varies with the temperature of the environment; cold blooded.

endothermic: Having a body temperature that remains relatively constant regardless of the temperature of the environment; warm blooded.

egestion: The elimination of undigested material from the digestive tract.

electron transport chain: A series of oxidation reduction reactions in which most of the energy produced from the breakdown of glucose is transferred to ATP.

embryo: A multicellular organism in the early stages of development.

embryo - sac: The mature female gametophyte of a flowering plant.

endoderm: The inner layer of cells in a simple animal or embryo; one of the germ layers of an animal embryo.

endodermis: In plants, the innermost layer of the cortex of the root.

endoplasmic reticulum: A system of membrane enclosed, fluid filled canals that form a network through the cytoplasm of a cell.

endosperm: The tissue that develops from the endosperm nucleus, often serving as a food supply for the plant embryo.

enzyme: A protein that acts as a catalyst increasing the rate of a specific chemical reaction.

epicotyl: The part of a plant embryo above the point of attachment of the cotyledons; gives rise to the terminal bud, leaves and stem.

epidermis: In plants, a protective tissue that forms the outer layer of leaves, green stems, and roots. In animals, the outer layers of skin consisting of tightly packed epithelial cells.

epithelial tissue: A type of tissue that covers body surfaces and lines body cavities and organs.

eukaryote: A cell containing a membrane bounded nucleus.

euglenophyta: A phylum of protists; euglenoids show both plant-like and animal-like characteristics.

evolution: The theory that alike arose by natural processes at an early stage of the earth's history and that complex organisms developed from simple organisms by a process of gradual change.

exoskeleton: A skeleton found on the outside of the body, enclosing the soft parts.

F

family: A group of related genera.

fatty acids: A type of organic molecule having a carbon chain with atleast one carboxyl group attached to it; one of the end products of the digestion of fats.

feces: Undigested and indigestible food material that is solidified in the large intestine and then eliminated from the body.

fermentation: A series of reactions occurring in the absence of free oxygen during which pyruvic acid is converted to alcohol, lactic acid or other product.

fertilization: The union of an egg cell nucleus and a sperm cell nucleus to form a zygote.

filament: The stalk like part of a stamen that supports the anther.

flagellum (pl-flagella): A long, hair like organelle at the surface of a cell, with the capacity for movement.

florigen: A plant hormone which induces flowering.

fossil: The remains or traces of an extinct organism.

fruit: A structure that develops from the ovary and other associated flower parts after fertilization and that contains the seed.

fungi: A group of thallophytes without chlorophyll.

gamete: A monoploid cell that fuses with another monoploid cell to form a zygote; a sperm cell or egg cell.

gametogenesis: The process by which gamete develops.

gene: A distinct unit of hereditary material found in chromosomes.

gibberellin: A hormone that affects plant growth as well as the development of fruits and seeds.

glycerol: An alcohol; one of the end product of digestion of fats.

glycogen: A food storage carbohydrate in animals and many fungi.

glycolysis: The early phase of respiration in which glucose is converted to pyruvic acid with the release of a small amount of useful energy.

gonads: In animals a specialized organ in which gametes develop.

grafting: A type of artificial vegetative propagation accomplished by permanently joining a part of one plant to another plant.

growth: The process by which living organisms increase in size.

guanine: A nitrogenous base found in DNA and RNA.

guard cell: In leaves a specialized epidermal cell that regulates the opening and closing of stomata.

guttation: The normal physiological process of plant of exuding moisture from an uncut surface.

gymnosperms: A seed plant where seeds are not enclosed within a fruit.

gynoecium: The female organ of a flower, a collective name for carpels.

H

haploid: Having half the diploid number of chromosomes, n or monoploid.

helix: A shape like a coiled spring, used to describe the structure of DNA molecules.

haemoglobin: A red, iron containing pigment that carries oxygen in the red blood cells of vertebrates that increases the oxygen carrying capacity of the blood.

herbaceous stem: A stem that is soft, green and juicy.

herbivore: A heterotroph that feeds only on plants.

hermaphrodite: An individual organism that possess both testes and ovaries.

heterotroph: An organism that cannot synthesize its own food and must obtain it ready-made.

heterozygous: Having two different alleles for a trait.

homologous pair: A pair of chromosomes having the same size and shape and carrying alleles for the same trait.

homologous structures: Structures found in different kinds of organisms that have the same basic arrangement of parts and a similar pattern of embryonic development.

- Homo sapiens:** The species of modern humans.
- homozygous:** Having two identical alleles for a trait.
- hormone:** A substance that is secreted by a gland directly into the blood stream and that produces a specific effect on a particular tissue.
- horsetail:** A spore dispersing member of the tracheophytes, having a hollow green stem and a collar of leaves at intervals along stem.
- humus:** The dark, rich organic matter in topsoil formed from the decay of dead plants and animals.
- hypha (pl-hyphal):** A threadlike filament many of which make up the bodies of most fungi.
- hypocotyl:** The part of a plant embryo between the radicle and the point of attachment of the cotyledons.
- hypothesis:** A possible explanation of an observed set of facts.

I

- insectivora:** An order of generally small, primitive mammals that feed mainly on insects; includes moles, shrews and hedgehogs.
- insulin:** A hormone secreted by the pancreas that lowers blood-glucose levels.
- intercellular fluid:** The colourless, watery fluid that bathes all the cells of the body; interstitial fluid.
- internal fertilization:** The process in which eggs are fertilized within the body of the female.
- interphase:** The stage of the cell reproductive cycle lasting from the end of one mitotic cycle to the beginning of the next.

L

- lateral bud:** A bud in the upper angle where a leaf joins a stem; axillary bud.
- layering:** A type of artificial vegetative propagation, accomplished by covering part of a growing plant with soil.
- leaf:** A usually thin, flat, outgrowth of a stem, carries out photosynthesis
- lenticel:** An opening in cork tissue that allows the exchange of respiratory gases between the atmosphere and the plant tissues.
- lepidoptera:** An insect order having two pairs of broad, membranous wings, butterflies and moths.
- leucoplast:** A colourless plastid in which glucose is converted to starch.
- light reactions:** In photosynthesis, a series of reactions requiring light in which water or some other compound is oxidized and ATP and NADPH₂ are produced.

M

- marsupial:** Non placental mammal in which the fetus is born at a very immature stage and completes its development in a pouch on the mother's body.
- medusa:** The body form of free swimming coelenterates.
- meiosis:** Cell division in diploid cells that results in haploid cells; reduction division.
- meristem:** In a plant, a region or tissue composed of cells that undergo or are capable of repeated cell division.

- meristematic zone:** A region of actively dividing cells just behind the root cap.
- mesoderm:** The germ layer between the endoderm and ectoderm.
- mesophyll:** A layer of photosynthetic tissue found between the epidermal layers of a leaf.
- messenger RNA (mRNA):** The type of RNA that carries the code for a polypeptide from DNA to the ribosomes where it is translated.
- metabolism:** All the chemical reactions of the life processes of an organism.
- metamorphosis:** The series of changes that certain types of organisms undergo as they develop from a larva or nymph to an adult.
- metaphase:** The stage of mitosis or meiosis during which the centromeres of the chromosomes are lined up at the equatorial plane.
- microfilament:** Long, threadlike strands found in the cytoplasm of some cells, involved in movement.
- micropyle:** A small opening in the ovule through which the pollen tube grows.
- microtubule:** A long, cylindrical organelle found in cilia and flagella.
- mitochondrion:** An oval membrane enclosed organelle in which most of the reactions of cellular respiration occur.
- mitosis:** The process by which the nucleus of a cell divides, while maintaining the chromosomes number.
- monera:** The kingdom that includes the simplest one celled organisms, the bacteria and blue green algae; monerans.
- monocot:** A flowering plant whose seeds have one cotyledon.
- myxomycota:** A phylum of protists with characteristics of both protozoa and fungi during their life cycles; slime molds.

N

- nematoda:** A phylum of invertebrates with cylindrical bodies covered by a heavy cuticle; roundworms.
- nomenclature:** The system for naming organisms.
- nucleolus:** A dense, granular body that is found in the nucleus of cells and that is a site of RNA production.
- nucleotide:** The basic unit of nucleic acids, containing a sugar, a phosphate group, and one of four nitrogenous bases.
- nucleus:** In a eukaryotic cell, a large membrane enclosed organelle that contains the cell's DNA. In an atom, the central core of the atom, containing protons and neutrons.

O

- omnivore:** A heterotroph that feeds on both plants and animals.
- oogenesis:** The formation of eggs.
- oomycota:** A group of mainly aquatic fungi with flagellated spores and distinctly male and female gametes; water molds.
- oral groove:** The opening in the paramecium through which food is ingested.
- order:** A group of related families.

organ: A body part composed of specialized tissues performing a specific function.

organ system: A group of organs that works together to perform a general function.

organelle: A specialized structure in the cytoplasm of a cell that carries out a specific function.

organism: An individual living thing.

osculum: An opening at the unattached end of a sponge that serves as the excurrent opening.

osmosis: The diffusion of water across a semi permeable membrane from a region of high concentration of water to a region of low concentration of water.

osmotic pressure: The increase in pressure resulting from the flow of water in osmosis.

ovule: In seed plants, a structure within the ovary that contains a female gametophyte and that develops into a seed after fertilization.

oxidation: A type of chemical reaction in which an atom or molecule losses electrons or hydrogen atoms.

oxidation reaction: A reaction in which one substance is oxidized and another substance is reduced.

P

palisade cells: The regularly arranged, tightly packed cells filled with chloroplasts that make up the upper layer of the mesophyll of the leaf.

parasite: A heterotroph that obtains nutrients from the living organism in or on which it lives.

passive transport: A process by which materials move across cell membranes without the expenditure of cellular energy.

pedicel: The stalk that bears a single flower.

pellicle: A grooved, flexible proteinaceous structure found inside the cell membrane of some protists.

peptide bond: The bond formed between two amino acids by elimination of a molecule of water.

petal: One of the usual showy flower structures located between the sepals and the stamens.

petiole: The structure that attaches the leaf to the stem of a plant.

pH: A unit that indicates the concentration of hydrogen in a solution, a measure of the acidity of a solution.

phagocytosis: The process in which large particles or small organisms are ingested in a cell.

phloem: The tissue that conducts food and other dissolved materials throughout the body of a vascular plant.

photoperiodism: The response of a plant to the changing duration of light and darkness during the year.

photosynthesis: The process by which organic compounds are synthesized from inorganic carbon i.e. CO_2 , in the presence of light in most autotrophic organisms.

phylum: The largest or most inclusive group within a kingdom.

pigment: A substance that absorbs only certain wavelength of light, a substance that has colour.

pinocytosis: The process in which liquids or very small particles from the surrounding medium are taken into a cell by an inpocketing of the cell membrane.

pistil: The part of a flower that contains the ovules and through which pollen tubes grow.

pith: The centre of a herbaceous dicot stem, made up of parenchyma cells.

plankton: Organisms that float in a body of water.

plantae: One of the five kingdoms, its members are mostly multicellular and photosynthetic; plants.

plasmid: A small, circular segment of DNA that is found in bacteria and that stays separate from the bacterial chromosome, used in genetic engineering.

plasmolysis: The shrinking of cytoplasm resulting from loss of water by osmosis in a cell placed in a hypertonic solution.

plastid: A membrane enclosed organelle found in the cells of some protists and almost all plants, includes chloroplasts, chromoplasts, and leucoplasts.

pollen grain: The male gametophyte of seed plants.

pollen tube: The tube like outgrowth of the pollen grain through which the sperm nuclei pass to the ovule.

pollination: The transfer of pollen from an anther to a stigma of a flower.

polymer: A large molecule consisting of chains of repeating units.

polyp: The sessile body form of a coelenterate

polypeptide: A chain of amino acids joined by peptide bonds.

polysaccharide: A long chain of repeating sugar units formed by joining simple sugars by dehydration synthesis.

primary root: The first structure to emerge from a sprouting seed.

prokaryote: A cell that lacks a distinct, membrane bounded nucleus; a moneran; a bacterium or blue green alga.

protein: A compound consisting of one or more chains of amino acids.

protista: A kingdom that includes simple, mostly unicellular, eukaryotic organisms; protists.

purine: A type of nitrogenous base found in DNA and RNA; adenine and guanine.

pyrimidine: A type of nitrogenous base found in DNA and RNA; thymine, cytosine and uracil.

R

radial symmetry: A type of symmetry in which any section through and parallel to the central axis of the organism divides it into similar halves.

reactant: Any of the substances participating in a chemical reaction.

receptacle: The expanded end of the pedicels to which the flower parts are attached.

recombinant DNA: DNA that has been altered by genetic engineering.

recombination: The formation of new combinations of alleles resulting from crossing-over and independent assortment during meiosis, and from gamete fusion.

reduction: A type of chemical reaction in which an atom or molecule gains electrons or hydrogen atoms.

respiration: The process by which organisms obtain the energy they need by releasing chemical energy stored in nutrients.

rhizome: A thick, horizontal stem containing stored food, which forms new plants by vegetative reproduction.

ribosomal RNA: A type of RNA transcribed from DNA in the nucleolus and found in the ribosomes.

ribosome: An organelle that is the site of protein synthesis in a cell.

RNA (ribonucleic acid): The nucleic acid that is transcribed from DNA.

root pressure: The osmotic pressure in the xylem of a root.

runner: A horizontal stem with long internodes that forms independent plant by vegetative production; a stolon.

S

salivary gland: A gland that secretes saliva into the mouth.

sepal: One of several leaflike structures at the base of a flower.

seta: One of the tiny bristles on the body segments of annelids, used in locomotion.

sexual reproduction: A form of reproduction in which a new individual is produced by the union of the nuclei of two specialized sex cells i.e., gametes, usually from two separate parent organisms.

solute: A substance dissolved in a solvent.

solution: A mixture, usually liquid, in which one substance in the form of molecules or ions, is uniformly distributed through another substance.

solvent: The liquid substance that makes up the bulk of a solution.

somatic cell: A body cell, as distinguished from a sex cell.

species: All organisms of one kind that can interbreed in nature.

spindle: A structure formed by fibers during mitosis.

spongy mesophyll: The lower portion of mesophyll in a leaf, consisting of irregular shaped, chloroplast-filled cells separated by large air spaces.

spore: A specialized reproductive cell that can give rise to a new organism.

sporophyte generation: The diploid, spore producing generation in a plant with an alternation of generations.

stamen: The organ of a flower that bears pollen grains.

starch: A polysaccharide that is the main food storage compound in plants.

stem: The leaf-bearing structure of a vascular plant.

stigma: In a pistil, the enlarged, sticky knob on top of a style that receives the pollen, in protists, an eyespot.

stolon: In fungi a hypha that grows over the surface of food; in vascular plants, a runner.

stomata: An opening in the epidermis of leaves that allows the exchange of respiratory gases between the internal tissues of the leaf and the atmosphere.

style: In flowers, the part of the pistil between the stigma and the ovary.

synthesis: A process in which simple substances are combined chemically to form more complex substances.

T

tadpole: The larval form of a frog or toad.

taxonomy: The branch of biology that deals with the classification and naming of living things.

telophase: The stage of mitosis during which the chromosomes uncoil, the spindle and asters disappear, and the nuclear membrane reforms.

thymine: A nitrogenous base found in DNA.

tissue: In multicellular organisms, a group of cells that are similar and are organized into a functional unit; usually integrated with other tissues to form an organ.

tracheophyta: The phylum of vascular plants contains the water-conducting and food-conducting tissues i.e., xylem and phloem; tracheophytes.

transduction: The process in which pieces of DNA are transferred from one bacterial cell to another by viruses.

transfer RNA: The type of RNA that carries a particular amino acid to mRNA at the ribosome in protein synthesis.

transport: All the processes by which substances pass into or out of cells and circulate within the organism.

trochophore: A type of free-swimming, ciliated larva.

tropism: A growth response in a plant caused by an environmental stimulus that comes primarily from one direction.

tube foot: In echinoderms one of many water filled tubes ending in a suction disk; used in locomotion, feeding and respiration.

tuber: An enlarged portion of an underground stem that can grow into a new plant by vegetative reproduction.

turgor pressure: The pressure against a plant cell wall resulting from the osmotic flow of water into the cell.

U

uracil: a nitrogenous base that is found in RNA but not in DNA.

V

vaccine: An injection of dead or weakened bacteria or viruses or modified bacterial toxins that produce an active immunity.

vacuole: A membrane-enclosed fluid-filled cavity in a cell.

vascular bundle: A structure within a stem containing parallel strands of xylem and phloem; may also contain cambium.

vascular cambium: The meristematic layer of cells that causes secondary growth in width of a stem or root.

vascular tissue: The xylem and phloem of a plant; conducting tissue.

vegetative reproduction: The process in which undifferentiated plant cells divide mitotically and then differentiate to form an independent plant; vegetative propagation.

vertebrata: A subphylum of chordates having an enlarged brain and a spinal column made up of vertebra that enclose the dorsal nerve chord; vertebrae.

virus: An extremely small particle of DNA or RNA surrounded by a protein coat and capable of reproducing itself inside a living cell.

W

woody stem: A stem containing wood.

X

xylem: The tissue that conducts water and minerals from the roots upward through the plant and helps to support the plant.

Y

yellow-green algae: Members of the phylum Chrysophyta; mostly unicellular, fresh-water organisms.

yolk: Stored food in an animal egg.

yolk sac: In shelled eggs, the extra embryonic membrane that surrounds the yolk, containing blood vessels that transport food to the embryo; in mammals, an extraembryonic membrane that forms part of the umbilical cord.

Z

zoology: A branch of biology that deals with the study of animals.

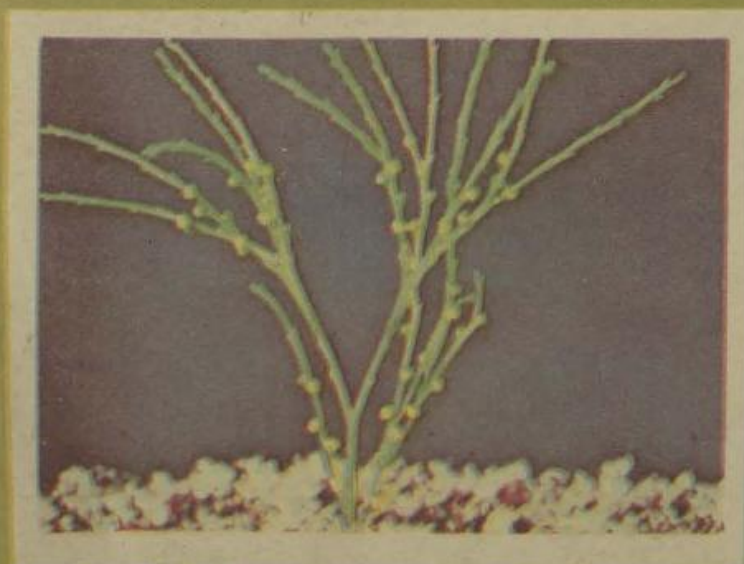
zooplankton: Small animal and nonphotosynthetic protists that float near the surface of water.

zygospore: A zygote covered by a thick, protective wall.

zygote: The diploid cell resulting from fusion of two gametes.

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